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COVER ART:
A collage of images representing the Space Science Division's search for life in, and the understanding of, the universe.

Images:

- -Hubble Space Telescope picture of nebula NGC 3603.
- -Fertilized human egg.

(Artwork: James Schilling)

Space Science Division

2000 Annual Report

National Aeronautics and Space Administration

Ames Research Center Moffett Field, CA 94035-1000



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Space Science Division Personnel

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Space Science Division (SS) Overview

he Space Science Division at NASA's Ames Research Center conducts research and mission-related activities that are structured around the study of the origins and evolution of stars, planetary systems, and life, and that address some of the most fundamental questions pursued by science, questions that examine the origin of life and our place in the universe, and questions that lie at the heart of the emerging discipline of Astrobiology.

Ames is recognized as a world leader in Astrobiology, defined as the study of life in the universe and the chemical and physical forces and adaptations that influence life's origin, evolution, and destiny. In pursuing this primary Center mission in Astrobiology, scientists in the Space Science Division perform pioneering basic research and technology development to further fundamental knowledge about the origin, evolution, and distribution of life within the context of cosmic processes. To accomplish this objective the Division has assembled a multidisciplinary team of scientists including astronomers, astrophysicists, chemists, microbiologists, physicists, and planetary scientists. It also requires access to the space environment, since many of the critical data needed to elucidate the evolutionary steps outlined above are only available in space in star-forming regions, in the interstellar medium, and in and around planetary environments.

Major elements of the Space Science Division's program include the study of the interstellar gas and dust that form the raw material for stars, planets, and life; the processes of star and planet formation; the evolution of planets and their atmospheres; the origin of life and its early evolution on the Earth; the search for past or present life throughout the solar system with emphasis on Mars; and advanced technologies for robotic and human exploration of space.

Space Science Division personnel participate in a variety of major NASA missions. Division scientists are/were Investigators, Team Members, or Interdisciplinary Scientists on Pioneer, Voyager, Galileo, Pathfinder, the Infrared Space Observatory, the Cassini mission to Saturn, Stardust, Mars Global Surveyor, and the Kuiper Airborne Observatory. Division scientists are also involved in the development of experiments for International Space Station, the Stratospheric Observatory for Infrared Astronomy (SOFIA), planetary detection with Kepler, Astrobiology Explorer, Pascal Mars Scout mission, the Space Infrared Telescope Facility (SIRTF), and Next Generation Space Telescope (NGST).

The programs in the Space Science Division are international in scope, ranging from active participation in international scientific meetings and societies, to collaborative ground-based research projects, to scientific investigations on international flight missions and projects.

Extensive ties are maintained with the academic community through collaborative research programs and development of science curricula materials, and additionally, students at all levels represent a significant component of the Division's on-site research work force.

The Space Science Division represents a unique resource for NASA's Astrobiology thrust and for the Agency's current and future manned and unmanned missions. The total science and mission capability of the Space Science Division described here is unmatched by any other NASA Center or national laboratory.

The Division is organizationally divided into four Branches named according to the focus areas of the research conducted by the scientists in those Branches: Astrophysics, Astrobiology, Exobiology, and Planetary Systems (see Figure 1).

In 2000, the Division employed 79 civil service personnel, approximately 50 of whom are Ph.D. scientists. This core permanent staff is augmented with approximately 125 non-civil servant scientists and technical support personnel who are resident in Division facilities through mechanisms such as grants, cooperative agreements, support contracts, fellowships, visiting scientist positions, and student internships.

It is common for visiting scientists to spend their summer research or sabbatical time in the Division's laboratories and facilities. Extensive ties are maintained with the academic community through collaborative research programs and also through the development of science curricula materials. The Space Science Division is dedicated to fostering greater interest in careers in the sciences and provides unique opportunities for training the next generation of scientists. Students at all levels – high school, undergraduate, graduate, and post-doctoral – represent a significant component of the Division's on-site research work force. In 2000, approximately 20 National Research Council Postdoctoral Fellows and 10 undergraduate students were resident in the Division. Division personnel also mentored students in the Astrobiology Academy, a competitive program for college undergraduates to participate in hands-on research projects here at Ames Research Center.

In the following section of the Annual Report, the research programs of each Branch are summarized. Within each area, several examples of research topics have been selected (from a total of approximately 130 tasks) for more detailed description. Following that section is a list of publications authored by Division personnel with 2000 publication dates. Finally, if a particular project is of interest, the personnel roster that begins on page 77 may be used to contact individual scientists. \square

Donald L. DeVincenzi

Chief, Space Science Division http://www-space.arc.nasa.gov

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Figure 1: Space Science Division Organization Chart



Astrophysics Branch (SSA) Overview

Scientists in the Astrophysics Branch pursue a wide range of laboratory and observational astronomy research. The Branch is particularly interested in studying the physical and chemical properties of astronomical phenomena by observing their radiation at infrared (and ultraviolet) wavelengths, beyond the range of visible light.

Planets, stars, and the interstellar medium of the Milky Way and other galaxies are rich in infrared spectral features which provide clues to their origins, physics, chemistry, and evolution. SSA researchers use state-of-the-art laboratories, ground-based, airborne, and space-based observatories to conduct their research. Astrophysics Branch scientists, engineers, and technicians also play key roles in developing new NASA space and airborne missions and instruments such as SIRTF, NGST, and SOFIA. The primary products of the Astrophysics Branch are new observations of the universe and new instrumentation developed to make these observations.

Jesse Bregman

Deputy Chief, Astrophysics Branch (SSA)

IDENTIFYING POLYCYCLIC AROMATIC HYDROCARBONS IN SPACE

Jesse Bregman and Pasquale Temi

Polycyclic aromatic hydrocarbon (PAH) molecules are the most abundant family of molecules in the interstellar medium after molecular hydrogen and carbon monoxide, and contain about 10% of all the interstellar carbon. They are extremely tough molecules, are a component of meteorites, and thus were likely delivered to the early earth where they may have played an important role in the formation of life. Until recently, the only way to study PAHs in the interstellar medium by examining their emission spectrum. PAHs fluoresce when present near sources of bright ultraviolet radiation such as exits in planetary nebulae and HII (ionized hydrogen) regions. PAH absorption spectra have been measured in laboratory studies, but these spectra cannot be directly used to determine the mix of PAHs that occur in the interstellar medium without using complex models. There are enough unknowns in the models that definitive statements about the exact nature of the interstellar PAHs has so far been impossible.

Recently, a spectral database has become available from the Infrared Space Observatory that contains objects in which we have found the C-H PAH stretch feature (near 3.26 µm) in absorption. Using the database of isolated neutral PAHs generated by the Ames Astrochemistry Laboratory, we can match the interstellar feature fairly well with a mixture of PAH molecules. However, the mixture is not unique and does not tell us which particular PAHs are present in space. This is demonstrated in Figure 2 which shows two fits to the absorption observed towards the protostellar source S140. The laboratory database contains only a few PAHs as large as those expected to survive the rigors of the interstellar medium, so it is perhaps not surprising that a precise match is still not possible. Techniques for obtaining lab spectra of larger PAHs exist, but making large PAHs for lab studies is very difficult. Once such lab data exist, being able to directly compare lab and interstellar spectra without using uncertain models could provide the first identification of individual PAHs in space. \Box

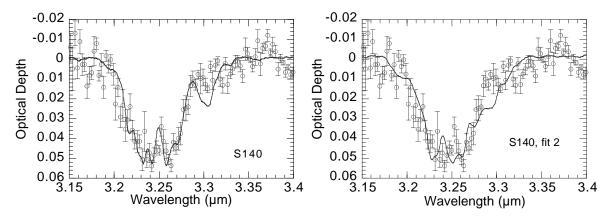


Figure 2: The spectrum of S140 has been divided by an estimate of the continuum to allow direct comparison with laboratory data of PAHs. The two panels show different mixtures of laboratory PAHs (solid lines) plotted on top of the S140 data points.

THE AIRES FAR INFRARED DETECTOR ARRAY

Edwin Erickson, Jessie Dotson, Jam Farhoomand, Christopher Mason

A unique, state-of-the-art array of detectors is being developed as part of AIRES, the Airborne Infrared Echelle Spectrometer for SOFIA (the Stratospheric Observatory for Infrared Astronomy). SOFIA is a Boeing 747 which will carry a 2.7-meter telescope to operating altitudes up to 45,000 feet. It is under development by NASA and the DLR (German aerospace center). SOFIA is scheduled to begin operations at Ames in late 2004. AIRES — which is being built at Ames — is the facility spectrometer for SOFIA. AIRES will measure atomic and molecular spectral lines at far-infrared wavelengths, roughly 30 to 400 times the wavelengths of visible light, to probe physical characteristics of astronomical sources such as star forming regions and our Galactic center.

Here we describe highlights of the AIRES detector development. Infrared light collected by the SOFIA telescope will be distributed by the optical system of AIRES to its semiconductor detectors so as to permit simultaneous separation of different wavelengths in each of 24 imaging picture elements (pixels) viewing the sky. The detectors will be arranged in a 16x24 rectangular grid with pixels spaced 8 hundredths of an inch apart. Each detector is a chip of antimony-doped germanium mounted in an integrating cavity and fed with light from the spectrometer by a conical light collector, shown in Figure 3.

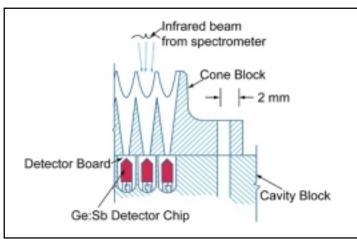


Figure 3: Detail of the AIRES far infrared detector geometry.

The AIRES optical system and detector assembly will be cooled in a cryostat to a few degrees Kelvin, as required to achieve the highest possible sensitivity to the infrared radiation collected by the SOFIA telescope. The detectors convert the light from the spectrometer into electrical signals. These are amplified and multiplexed by adjacent integrated circuits that route the signals to the data system outside the cryostat.

These unique multiplexing amplifiers were designed specifically for AIRES by industrial specialists collaborating with AIRES team members. The device technology was originally developed for SIRTF

(Space Infrared Telescope Facility), but the new circuits are tailored for the wider range of infrared backgrounds expected on SOFIA. They feature externally programmable gains to accommodate different observing conditions, and so will be suitable for a variety of SOFIA instruments as well as some spaceborne instruments. The AIRES team pioneered this development, and has tested several devices, confirming that their cryogenic noise and gain performance meets AIRES needs.

The entire detector package — detectors, amplifiers, and array assembly — is custom designed and built, with much of the work done at Ames by the AIRES team. In previous tests the detector configuration sketched in Figure 3 was shown to work well. During fiscal year 2000, testing of the amplifiers and design and fabrication of a 2x24 protoflight detector module have made great progress. This unique detector system, essential for AIRES' success, is well on its way to achieving its design performance. \Box

THE WORLD'S LARGEST GRATING

Michael R. Haas, James A. Baltz, Edwin F. Erickson, Emmett I. Quigley, and David C. Scimeca

The Airborne Infra-Red Echelle Spectrometer (AIRES) is a high-resolution grating spectrometer under development as a facility science instrument for the Stratospheric Observatory for Infrared Astronomy (SOFIA). An echelle is a grating used at a steep angle of incidence relative to the incoming light beam. The spectral resolution of a grating spectrometer is directly proportional to the projected length of its grating along this beam and inversely proportional to the wavelength of light being analyzed. AIRES is designed to measure far-infrared (long-wavelength) spectral lines of molecules and atoms originating in the interstellar medium. Therefore, AIRES requires a grating significantly longer than any previously made. In fact, the wavelength range and resolution planned for AIRES demands the World's largest grating!

Further, the entire AIRES optical system must be operated at a few degrees Kelvin (near absolute zero). To minimize problems associated with thermal contraction in this cryogenic environment, to facilitate diamond machining, and to ensure long-term stability, a monolithic aluminum blank was chosen. This blank was manufactured from 152-mm thick, aluminum alloy 6061-T651, Type 200 tooling plate. The final blank is 102 mm thick, 267 mm wide, and 1067 mm long with the corners removed to provide a near-elliptical planform. The blank was light-weighted by cutting triangular-shaped slots with a wire-electric-discharge machine, which builds less stress into the blank than conventional milling and has the ability to cut deep slots with small corner radii. The resulting truss-like structure is symmetric, provides good specific stiffness, and is 70% light weighted. Before final machining, the blank was heat-treated at $375 \infty C$ for two hours and then thermally cycled 7 times between $-200 \infty C$ and $100 \infty C$ to obtain the required stability.

A groove spacing of 980 microns, an apex angle of 90 degrees, and a blaze angle of 76 degrees were selected to optimize the packaging and optical performance of the grating at the wavelengths of

interest. This combination of parameters maximizes the spectral resolution for the 63- and 145-micron neutral oxygen, 157-micron singly ionized carbon, and 205-micron singly ionized nitrogen transitions arising from the interstellar medium, without adversely effecting performance for other high-priority transitions.

The grating was ruled under contract with Hyperfine, Incorporated of Boulder, CO, with a fly cutter using single-point diamond turning on a custom ruling engine. The completed grating is shown in Figure 4. The light-weighting truss structure is evident along its front edge. Two reflections of the technician are visible; the front reflection originates on the long, 14-degree groove facets and the rear reflection originates on the steep, 76-degree groove facets.

To achieve the desired optical performance, the AIRES optical system must have a total root-mean-square (RMS) wave-front error (WFE) less than 1.5 microns. A detailed error analysis apportioned 0.8 microns RMS WFE to the echelle grating. This WFE includes contributions from both absolute and periodic errors in groove position, shape, straightness, and fanning, as well as gross deflections of the blank due to self-weight, tool forces, and variations in thermal contraction. Interferometric tests of the completed grating measure a WFE of 0.3 microns RMS – much better than required. This implies that the surface is flat to about one part in 7 million. Other optical tests confirm that the efficiency and scattered light properties of this grating are acceptable for use in AIRES. The World's largest echelle grating has been successfully ruled and tested; the associated opto-mechanics, cryostat, detectors, and software for AIRES remain under development. \square



Figure 4: The AIRES echelle is the largest monolithic, fully-phased grating in the World.

THE SOFIA WATER VAPOR MONITOR

Thomas L. Roellig, Robert Cooper, Brian Shiroyama, Regina Flores, Lunming Yue, and Allan Meyer

The Stratospheric Observatory for Infrared Astronomy (SOFIA), a 3-meter class telescope mounted in a Boeing 747 aircraft, is being developed for NASA by a consortium consisting of the University Space Research Association, Raytheon E-Systems, and United Airlines. This new facility will be a replacement for the retired Kuiper Airborne Observatory that used to fly out of Moffett Field. As part of this development, NASA Ames Research Center is providing an instrument that will measure the integrated amount of water vapor seen along the telescope line-of-sight. Since the presence of water vapor strongly affects the astronomical infrared signals detected, such a water vapor monitor (WVM) is critical for proper calibration of the observed emission. The design and engineering model development of the water vapor monitor is now complete and the hardware to be used in the flight unit is being fabricated and tested.

The SOFIA water vapor monitor measures the water vapor content of the atmosphere integrated along the line-of-sight at a 40° elevation angle by making radiometric measurements of the center and wings of the 183.3 GHz rotational line of water. These measurements are then converted to the integrated water vapor along the telescope line-of-sight. The monitor hardware consists of three physically distinct sub-systems:

- 1) The Radiometer Head Assembly, which contains an antenna that views the sky, a calibrated reference target, a radio-frequency (RF) switch, a mixer, a local oscillator, and an intermediate-frequency (IF) amplifier. All of these components are mounted together and are attached to the inner surface of the aircraft fuselage, so that the antenna can observe the sky through a micro-wave-transparent window. The radiometer and antenna were ordered from a commercial vendor and have been modified at Ames to include an internal reference calibrator. Laboratory tests of this sub-assembly have indicated a signal-to-noise performance over a factor of two better than required.
- 2) The IF Converter Box Assembly, which consist of IF filters, IF power splitters, RF amplifiers, RF power meters, analog amplifiers, A/D converters, and an RS-232 serial interface driver. These electronics are mounted in a cabinet just under the radiometer head and are connected to both the radiometer head and a dedicated WVM computer (CPU). All of the flight electronics boards have been fabricated and have been shown through testing to meet their requirements. A small microprocessor that handles the lowest level data collection and timing has been programmed in assembly language to collect and co-add the radiometer data and communicate with the software residing in the WVM CPU.

3) A dedicated WVM CPU that converts the radiometer measurements to measured microns of precipitable water and communicates with the rest of the SOFIA Mission and Communications Control System (MCCS). A non-flight version of this computer hardware has been procured for laboratory testing and the flight software is under development, with approximately 60% of the software coded and unit-tested. Proper command and data communications between the Water Vapor Monitor and the SOFIA MCCS have been demonstrated using an MCCS simulator located on-site at Ames that has been developed by the SOFIA Project. \Box

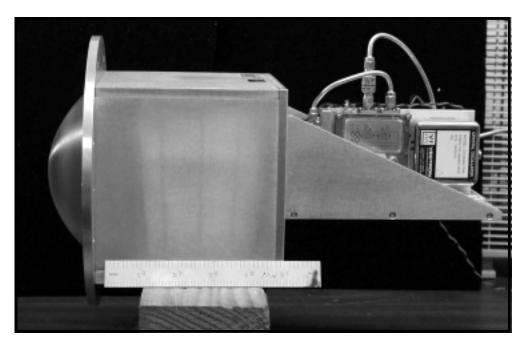


Figure 5: The SOFIA Water Vapor Monitor 183 GHz Radiometer Assembly

AMES NEW INTERSTELLAR SIMULATION CHAMBER. CAVITY RING DOWN SPECTROSCOPY OF INTERSTELLAR ORGANIC MATERIALS

Farid Salama, Ludovic Biennier, Robert Walker, Lou Allamandola, Jim Scherer, and Anthony O'Keefe

A major milestone has just been achieved at Ames. A new facility has been developed to directly simulate gaseous molecules and ions at the low temperature and pressure conditions of interstellar space. This laboratory facility -that is unique within NASA- combines the techniques of Supersonic Free-Jet Expansion Spectroscopy (JES) with the techniques of Cavity Ring Down Absorption Spectroscopy (CRDS). The principle objective is to determine the spectroscopic properties of large interstellar aromatic molecules and ions under conditions that precisely mimic interstellar conditions. The aim of this research is to provide quantitative information to analyze astronomical spectra in support of NASA's Space Science and Astrobiology missions, including data taken with the Hubble Space Telescope.

Understanding the origin, physical properties, and distribution of the most complex organic compounds in the universe is a central goal of Astrophysics and Astrobiology. To achieve this requires generating and maintaining large carbon-containing molecules and ions under interstellar-like conditions while simultaneously measuring their spectra under these conditions (i.e., in the gas phase at very low densities and at very low temperature). As an aside, these organic structures are those that constitute the building blocks of carbon nanotubes. This has been accomplished by combining three advanced techniques: free supersonic jet expansion, low-temperature plasma formation and the ultrasensitive technique of cavity ring down spectroscopy. The new facility comprises thus a pulseddischarge, supersonic slit jet source mounted in a high-flow vacuum chamber and coupled to a cavity ring down spectrometer. Under these experimental conditions, a beam of argon or helium gas seeded with polycyclic aromatic hydrocarbon molecules (PAHs) is expended in the gas phase into the cavity ring down chamber. When the expanding beam is exposed to a high-voltage ionizing electronic discharge, positively charged ions are formed that are characterized by very low, interstellar-like, rotational and vibrational temperatures (temperatures of the order of 10 and 100 K respectively are achieved this way as shown in Figure 6). Recording the cavity ring down signal is a direct measurement of the absolute absorption by the seeding molecules and ions. This is illustrated in Figure 7 that shows the spectrum of the PAH naphthalene ion $(C_{10}H_8^+)$. This unique experimental facility has been developed in collaboration with Los Gatos Research through a Small Business Innovative Research (SBIR) contract.

The data shown in Figure 7 can now be used to analyze the astronomical spectra. For example, the absorption band of the PAH ion $\rm C_{10}H_8^+$ shown in Figure 7 can be directly compared to the absorption spectrum of the diffuse interstellar bands (DIBs). These bands that contribute to the global interstellar extinction were discovered eighty years ago and remain an enigma to this day.

For the first time, the absorption spectrum of large organic molecules and ions can be measured under conditions that mimic entirely the interstellar conditions. \Box

Supersonic Free Jet Expansion

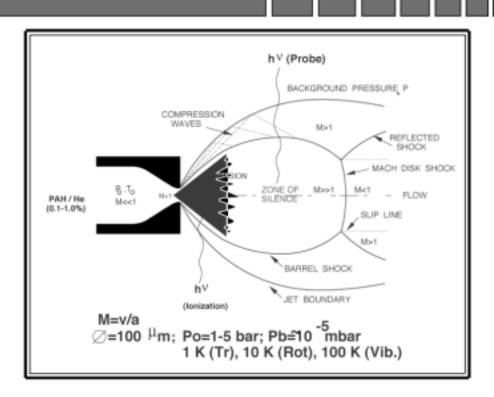


Figure 6: The figure shows the location of the "zone of silence" in a supersonic free jet expansion. The physical conditions within the boundaries of the "zone of silence" approach interstellar conditions.

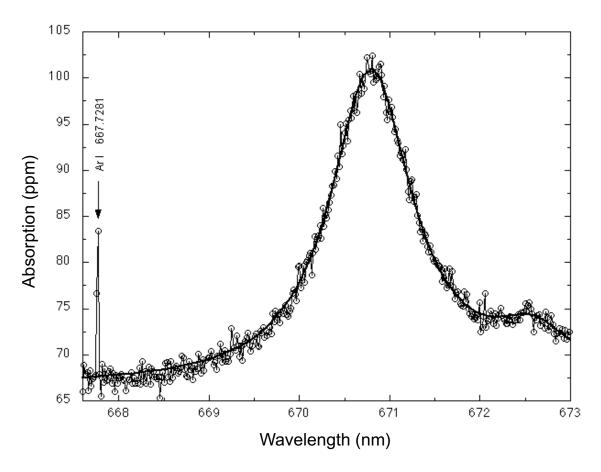
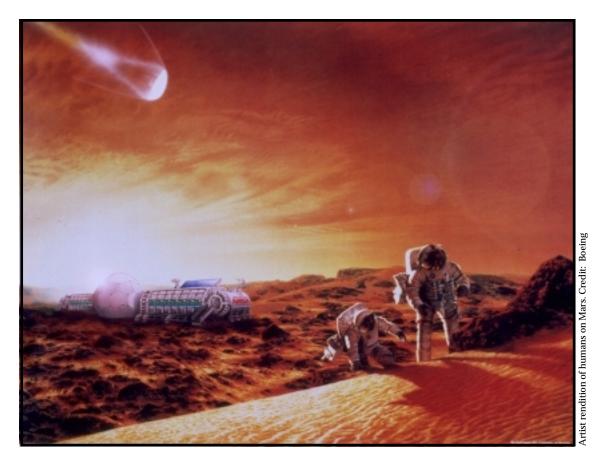


Figure 7: The CRDS absorption spectrum of the naphthalene cation ($C_{10}H_8^+$) under simulated interstellar space conditions. The spectrum is obtained when an argon free jet expansion seeded with naphthalene is exposed to a high-voltage discharge. Note the absorption line of metastable argon that is used for internal wavelength calibration.



Astrobiology Technology Branch (SSR) Overview

The Astrobiology Technology Branch supports fundamental research and the development of advanced technologies in astrobiology as they relate to the exploration of space and understanding life in the universe. Current branch efforts encompass research and technology development for advanced life support, utilization of planetary resources, and astrobiology. Advanced Life Support focused research is directed primarily at physicochemical processes for use in regenerative life support systems required for future human missions and includes atmosphere revitalization, water recovery, waste processing/resource recovery, and systems modeling, analysis and controls associated with integrated subsystems operation. In-Situ Resource Utilization (ISRU) technologies will become increasingly important on every Mars lander between 2003 and a human mission to Mars. The branch focus is on the development of technologies for Mars atmosphere acquisition, buffer gas production, and CO₂ compression. Research and technology development for astrobiology includes understanding the physical and chemical limits to which life has adapted on Earth, the molecular adaptations that have allowed living systems to inhabit extreme environments, and the application of this knowledge to biotechnology, nanotechnology, and planetary protection. Researchers in the branch also develop flight experiments and associated hardware for shuttle, ISS, and unmanned NASA missions.

Mark H. Kliss

Chief, Astrobiology Technology Branch (SSR)

ADVANCED LIFE SUPPORT POWER REDUCTION

Cory K. Finn

This research involves modeling of the power and energy usage of regenerative life support systems suitable for exploring the Moon and Mars. System energy integration and energy reuse techniques are being investigated, along with advanced control methods for efficient distribution of power and thermal resources. The high power requirements associated with food production and overall closed regenerative system operation remain as a critical technological challenge. Optimization of individual processors alone will not be sufficient to produce an optimized system. System studies must be used in order to improve the overall efficiency of life support systems.

Designs are being developed that match sources of waste heat, such as crop lighting and solid waste processing systems, with processes that can use this waste heat, such as water processing, food processing, food preparation, and heating of shower water, dish wash water or clothes wash water. Using energy integration techniques, optimal system heat exchange designs are being developed by matching hot and cold streams according to specific design principles. For various designs, the potential savings for power, heating and cooling are being identified and quantified, and estimates are being made of the emplaced mass needed for energy exchange equipment.

Advanced control system designs are also being developed that allow for more efficient distribution of resources, such as system cooling water or electrical power, in order to reduce system power requirements. More efficient energy usage can be achieved by allocating power and thermal resources in a dynamic fashion. Advanced control techniques, such as market-based control, can be used in order to smooth out system thermal and power loads. Reductions in the peak loading will lead to lower overall requirements. The controller dynamically adjusts the use of system resources by the various subsystems and components in order to achieve the overall system goals. A typical system goal would be the smoothing of power usage and/or heat rejection profiles, while maintaining adequate reserves of food, water, oxygen, etc., and not allowing excessive build-up of waste materials. Initially, computer simulation models are being used to test various control system designs. The most promising of these will be tested using a laboratory-scale life support system testbed at Ames Research Center.

Energy balance models are being developed to support both the energy integration and the dynamic resource allocation work. These models leverage off of existing mass flow models of regenerative life support systems developed at Ames Research Center. The heat exchange designs and control schemes developed as part of this NRA research will be provided to Johnson Space Center for use in the development of the ALS Systems Integrated Test Bed (also known as BIO-Plex) and in the design of flight hardware for Moon or Mars missions.

Currently, energy integration techniques are being applied to the life support problem. Several potential designs that would be suitable for various Mars missions have been selected for application of the energy integration analysis. Life support data have been collected, and an optimized heat exchange design has been developed for each scenario. For each design, the potential savings in energy and cooling has been estimated.

In addition to the energy integration work, advanced control system designs are being developed that allow for more efficient distribution of electrical power. A dynamic model of the BIO-Plex air loop has been created and serves as a platform for the development of active power management strategies. Several resource allocation objectives have been defined and tested. One objective that was considered was to reallocate power as needed to the various life support processors to eliminate surges in power usage over time. However, the reallocation of power was subject to constraints. For example, material storage levels needed to be maintained, as well as atmospheric conditions within the life support chambers. This power management system has been demonstrated using the simulation model and performed reasonably well. A second objective that has been and continues to be investigated is to smooth the demand for power throughout the system over time. \Box

SOLID-STATE COMPRESSOR FOR SPACE STATION OXYGEN RECOVERY

John Finn

At present, the life support system on the International Space Station Alpha vents overboard the carbon dioxide produced by the crew members. Recovering the oxygen contained in the CO_2 has the potential to reduce resupply mass by 2000 pounds per year or more, a significant weight which might instead be used for experiment payloads and other valuable items. The technologies used to remove CO_2 from air and to recover O_2 from CO_2 are flight-ready. However, the interface between the devices is a problem for the Space Station system. NASA Ames has developed a new technology that solves the interface issue, possibly allowing for the first time closure of the oxygen loop in a spacecraft.

The relevant part of the air revitalization system is shown in Figure 8. CO_2 produced by the crew is removed in the Carbon Dioxide Removal Assembly, or CDRA. This device effectively produces a pure CO_2 stream, but at a very low pressure. Elsewhere the oxygen generation system, which makes O_2 by electrolyzing water, produces a hydrogen stream. In principle the CO_2 and H_2 can react to form methane (CH_4) and water (H_2O) over a suitable catalyst. Water produced in this methane-formation reactor can be returned to the water electrolyzer, where the O_2 can be returned to the cabin. However, the methane-formation reactor requires CO_2 at a much higher pressure than that produced by the CDRA. Furthermore, the CO_2 and H_2 are often not available at the same time, due to power management and scheduling on the space station. In order to get the CO_2 to the reactor at the right pressure and at the right time, a device or assembly that functions as a vacuum pump, compressor, and storage tank is required.

One obvious solution to this problem is to use a mechanical vacuum pump/compressor combined with a high-pressure buffer tank. This has implementation problems, however. The rapidly moving parts of a mechanical compressor wear out relatively quickly, requiring frequent maintenance or replacement. The mechanical compressor can add noise and vibration to the sensitive station environment, unless large amounts of insulating material is provided. There is so little space available for the buffer tank that the compression ratio would have to be quite high. Finally the power required to compress the CO_2 to high pressure is considered very high for the power-limited Space Station.

The solution being developed by NASA Ames engineers uses a technique they originally developed for compressing the very low pressure Mars atmosphere so that it could be used in an in situ propellant production plant. The compressor uses a temperature-swing adsorption cycle and has no rapidly moving parts. Low-pressure CO_2 from the CDRA is adsorbed in a cool cylinder containing a sorbent material that has a high capacity for CO_2 . In this step, the device acts like a vacuum pump. Next, the cylinder stays in a standby mode until the CO_2 is required; i.e., the device acts like a storage tank. Finally, the cylinder is heated and the CO_2 is driven off the sorbent, producing CO_2 at a high pressure. The compressed CO_2 flows into the methane-formation reactor. Coolant from the Space Station's thermal control system cools the cylinder back to its initial state, and the process is repeated. Several such cylinders are combined in the device. They operate out of phase from each other, so that there is always a "vacuum pump" and a "compressor" available whenever they are needed by the processors on either side.

A single-bed prototype solid-state compressor was built at Ames and successfully tested with a high-fidelity CDRA at NASA Marshall Space Flight Center in 2000 (Figure 9). The temperature-swing adsorption compressor uses much less power than the mechanical compressor system and has far fewer parts. Its lifetime is estimated at ten years. It is free of vibration and noise, and is also smaller and lighter than its counterpart. \square

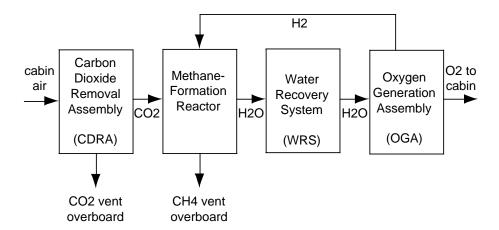


Figure 8: Carbon dioxide removal, carbon dioxide reduction, and oxygen generation planned for the International Space Station (methane-formation is not yet implemented). The compressor would be placed between the carbon dioxide removal and methane-formation reactor assemblies.

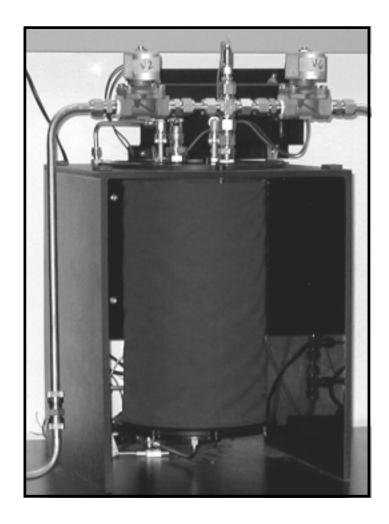


Figure 9: Single-bed prototype of a NASA Ames solid-state compressor.

DEVELOPMENT OF A WASTE PROCESSING INCINERATOR FOR LIFE SUPPORT

John W. Fisher

As space missions become longer, waste treatment on a space craft transitions from storage to reclamation of items such as activated carbon and carbon dioxide. Activated carbon and carbon dioxide can be reclaimed from hydrocarbon wastes such as paper, food scraps, and inedible plant biomass. Inedible plant biomass is produced when plants are grown in space to produce food. Growing plants consume carbon dioxide, and burning the inedible parts of a plant produces carbon dioxide that can be used to grow more plants. Unfortunately the process of burning, combustion, produces some toxic byproducts. One of the objectives of Ames' research on waste processing is to develop technology to burn waste and reclaim carbon dioxide without releasing toxic materials into the spacecraft.

The combustion process generally does well at completely oxidizing biomass to carbon dioxide and water. This is obvious from observation of the results of a typical wood fire. Only a small residue of inorganic substances, ash, is left in a fireplace after burning wood. The process of combustion of biomass in an incinerator operates in a similar way; the biomass is converted to gaseous products and inorganic ash. However, combustion in a fireplace typically takes place with wide fluctuations in temperature and composition as a function of time and position in the burning zone. Efficient combustors reduce the combustion fluctuation and achieve cleaner burning.

Fluidized combustion is a technology that provides good control of the combustion process and minimizes contaminants due to incomplete combustion. A fluidized bed consists of a bed of solid particles such as sand that behaves as a fluid. The fluidization occurs because a gas such as air is blowing up through the bed and causing the particles of the bed to float. Because sand is much denser than air, the bed holds much more heat energy than an equivalent amount of air. The heat energy held by the bed buffers the combustion process against the wide fluctuations in temperature that cause incomplete combustion.

Even in the best of combustors, however, some unoxidized material remains. In addition, some contaminants such as nitrogen and sulfur oxides are necessarily formed. In recent years Ames' research has focused on means to eliminate these byproducts. One approach has been to use reductive catalytic systems to convert the nitrogen and sulfur oxides to nitrogen and elemental sulfur – innocuous materials at room temperature. Oxidative catalysts can then oxidize the remaining hydrocarbon contaminants to very low levels.

In collaboration with outside university and corporate organizations Ames has developed and tested an integrated incineration system that utilizes a fluidized bed combustor followed by a catalytic cleanup system. This system has demonstrated the ability to burn inedible biomass and produce a very clean carbon dioxide product. The concentration of contaminants in the gas exiting the incinerator is generally less than a few parts per million. Except for the carbon dioxide itself (toxic to humans at high concentrations), the exit stream from the incinerator will be able to meet the Space Maximum Allowable Contaminant (SMAC) standards for clean air in a spacecraft.

When this system has been optimized for reliability and energy efficiency, it will be ready for testing in an advanced life support system that "closes the loop" on carbon. Carbon will travel in the system from plant to person to incinerator and back to the plant without ever becoming a stored waste. \Box

DEVELOPMENT OF THE VAPOR PHASE CATALYTIC AMMONIA REMOVAL PROCESS

Michael Flynn and Bruce Borchers

The Vapor Phase Catalytic Ammonia Removal (VPCAR) system technology represents the next generation in space flight water recovery systems. Water is the single largest resupply requirement associated with human space flight, accounting for 87% by mass of an astronaut's daily metabolic requirement. The VPCAR system achieves a mass metric almost an order of magnitude better than the current state of the art water processors. (Mass metric is a technique used to compare candidate technologies by reducing all performance parameters into a single equivalent launch mass metric.) Incorporating the VPCAR technology into human space flight missions could potentially save hundreds of millions of dollars in resupply costs, depending on the specific mission scenario. As a result, a human-rated version of the VPCAR technology has been authorized for development.

The human-rated system is being developed under contract to Water Reuse Technology (NAS2-00089). This is an external contract for the development and testing of the next generation VPCAR technology. We are currently about 1/2 way through a two year contracted development program. This activity is funded through Advanced Life Support program funds and a NASA peer reviewed NRA (00-HEDS-01)

Process Description

The VPCAR process is a two-step distillation based water processor. The current configuration of the technology is shown in Figure 10. A process flow diagram is provided in Figure 11. The VPCAR process is characterized by the use of a wiped-film rotating-disk (WFRD) vacuum evaporator to volatilize water, small molecular weight organics, and ammonia. This vapor stream is then oxidized in a vapor phase catalytic reactor to destroy any contaminants. The VPCAR process uses two catalytic beds to oxidize contaminants and decompose any nitrous oxide produced in the first bed. The first catalytic bed oxidizes organics to carbon dioxide and water, and ammonia to nitrous oxide and water. This oxidation reactor contains 1% platinum on alumina pellets and operates at about 523 K. The second catalytic bed reduces the nitrous oxide to nitrogen and oxygen. This reduction catalyst contains 0.5% ruthenium on alumina pellets and operates at about 723 K. The reactor and distillation functions occur in a single modular process step. The process achieves between 97-98% water recovery and has no scheduled maintenance or resupply requirements for a minimum of three years.

The VPCAR activity is significant in that it represents the development of the next generation of life support water recovery technology. Ames Research Center's involvement has spanned from the first principle definition to the model development, bench-scale and lab-scale prototype development, and most recently, contract management of the development of a human-rated version of the technology for evaluation for space flight application. \Box



Figure 10: Vapor Phase Catalytic Ammonia Removal (VPCAR) water recycling system.

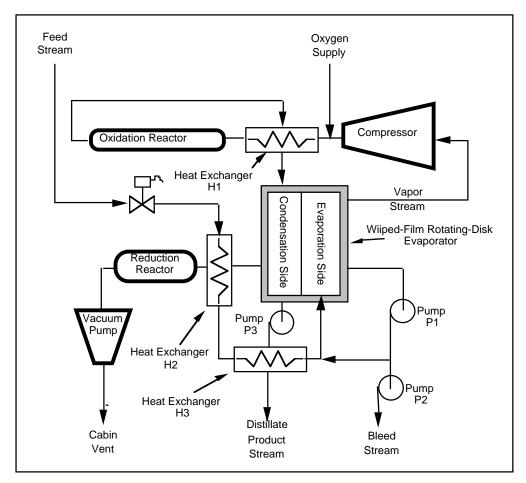


Figure 11: VPCAR Flow Diagram

PROTEIN NANOTECHNOLOGY

Jonathan Trent

In support of NASA's efforts to make missions "faster, better, and cheaper" there is a growing need for the development of smaller, stronger, and 'smarter' scientific probes compatible with space exploration. The necessary breakthroughs in this area may well be achieved in the revolutionary field of nanotechnology. This is technology on the scale of molecules, which holds the promise of creating devices smaller and more efficient than anything currently available. While a great deal of exciting research is developing around carbon nanotubes-based nanotechnology, we at NASA Ames Research Center are also exploring biologically inspired nanotechnology.

The biological 'unit,' the living cell, may be considered the ultimate nano-scale device. Cells, which are constructed of nano-scale components, are extremely sensitive, highly efficient environmental sensors capable of rapid self-assembly, flawless self-repair, and adaptive self improvement; not to mention their potential for nearly unlimited self-replicate. Ames is focusing on a major component of all cells (proteins) that are capable of self-assembling into highly ordered structures. A protein known as HSP60 is currently being studied that spontaneously forms nano-scale ring structures (Figure 12A, end view; B, side view), which can be induced to form chains (Figure 12C) or filaments (Figure 12D).

By using thermostable HSP60s, highly efficient methods have been developed for purifying large quantities of these proteins and by using the 'tools' of molecular biology, their composition and structure-forming capabilities are being currently modified.

For example, by removing a small fragment of the HSP60 protein, protein rings are produced that do not form chains or filaments, but continue to form rings that spontaneously assemble into highly ordered hexagonally-packed arrays (Figure 13A).

By further modifying each of these proteins so they bind metal atoms, these proteins can be used as a template to create an ordered pattern of metal on a surface with nanometer spacing. Ultimately the hope is to use such ordered arrays of metal to manufacture nano-scale electronic devices. Similarly, metal binding to proteins that form filaments (Figure 13B) may be used to create self-assembling nano-scale wires, which may someday be used to produce self-assembling circuits.

There are many potential applications for protein-based nanotechnology applicable to the production of smaller, stronger, and 'smarter' probes for NASA or more generally for applications in electronics and medicine. The combination of nanotechnology, information technology, and biotechnology at NASA Ames Research Center provides an excellent research environment for biologically-inspired nanotechnology. Analytical capabilities in nanotechnology provide essential tools for determining structure and function of protein-based systems. Supercomputing in information sciences provide capabilities essential for molecular simulations and biomolecule visualizations. Biotechn ology

provides the methodological basis for the genetic engineering essential for modifying and functionalizing protein structures. The goal is to establish the feasibility of creating useful protein-based nanostructures with applications for NASA and other critical areas of technology. \Box

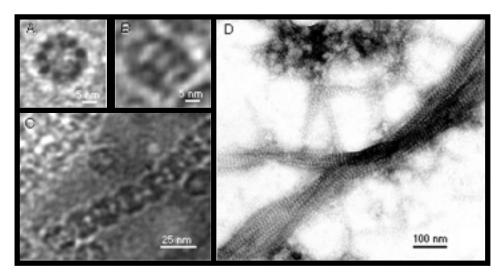


Figure 12: Protein rings (A end view, and B side view), chains of rings (C), and bundles of chains (D) that can be used in nanotechnology.

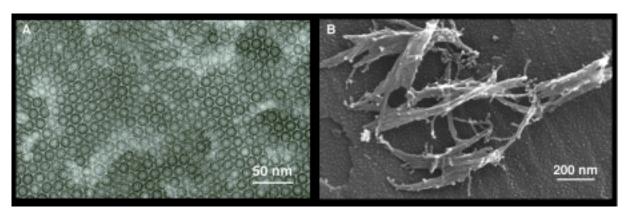
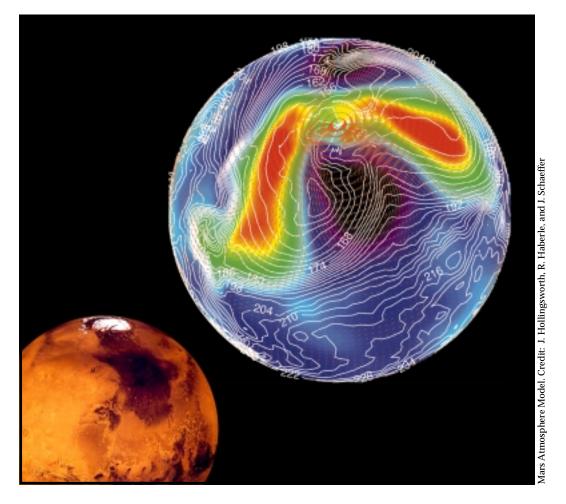


Figure 13: Modified proteins form hexagonally packed rings (A) or metal-containing protein filaments (B).



Planetary Systems Branch (SST) Overview

The overall research effort in the Planetary Systems Branch is directed at acquiring new, fundamental knowledge about the origins of stars and planetary systems and life itself. These studies are an integral part of NASA's overarching thrust in Astrobiology. Principal research programs include studies of the formation of stars and planets and the early history of the solar system, studies of planetary atmospheres and climate, investigation of the dynamics of planetary disks and rings, work on problems associated with the Martian surface including resource utilization and environments for the origin of life, and other programs (chiefly theoretical) involving stellar and planetary dynamics, radiative processes in stars and the interstellar medium, and investigation of the physical and chemical conditions in molecular clouds and star formation regions. Scientists in the branch also support NASA flight missions through participation on various mission science teams. The primary product of the Branch is new knowledge about the nature of the universe, presented and published in the open literature.

Bruce F. Smith

Deputy Chief, Planetary Systems Branch (SST)

PARTICLE-GAS DYNAMICS IN THE PROTOPLANETARY NEBULA

J.N. Cuzzi, R.C. Hogan, and A.R. Dobrovolskis

"Primitive" or unmelted asteroids, from which the planets were built, are represented in the meteorite record as a vast data set that has had little context for interpretation. The accretion of these primitive bodies from small grains and mm-sized, melted ''chondrules" almost certainly occurred in the presence of gas. Study of this stage is complicated by the feedback effects of the gas on the particles, and vice versa. Ames' efforts focus on numerical modeling of particle-gas interactions in turbulent flows, and understanding meteorite properties in the light of theoretical models.

Ames' "turbulent concentration" theory (TC), introduced several years ago, shows how particles of a specific size/density combination are concentrated by orders of magnitude in weak nebula turbulence. The theory makes specific predictions as to the relative abundance distribution of the concentrated particles. Predictions of the shape of the size distribution are in very good agreement with observed particle size distributions in primitive chondrites, thus revealing the fingerprints of TC. We developed a multifractal theory to predict the magnitude of turbulent concentration at much higher Reynolds numbers than achievable numerically, but the concentration factor can be so large that the local particle mass density can exceed that of the gas, and the feedback effect of the particle phase on damping the gas turblence must be considered before further modeling efforts can proceed. To better understand the effects of heavy mass loading on turbulence and TC, we are developing a cascade model of the process which is capable of reproducing the way concentrations of particles emerge as energy flows down the turbulent cascade, or inertial range. The cascade model is parametrized by partition functions or "multipliers" which are only statistically defined, but whose probability distribution function can be fit to our numerical results for mass-loaded turbulent fluids. That is to say, the multipliers appropriate for densely particle-enriched regions where the turbulent kinetic energy and/or vorticity might be damped, could be different from the multipliers in "normal" regions where mass loading is negligible. We are now determining the dependence of these multipliers on the local gas and/or particle density properties, making extensive use of new runs of a scalar field particle code (rather than the previous Lagarangian particle code) on the Ames Origins 2000 facility.

This year, Ames researchers also developed a scenario to help explain a new phenomenon found in chondritic meteorites by collaborators at Stanford and the University of Hawaii. The observation is an abundant class of Iron-Nickel metal grains with chemical and crystallographic properties that define their growth and cooling times simultaneously. The scenario developed visualizes a very hot, early, perhaps inner stage of the protoplanetary nebula, rather different from the environment in which more familiar chondrites form. In this dense, hot region, strong convection plumes rise towards the surface of the nebula, cooling and condensing small metal and silicate particles much as raindrops or hailstones condense in upwelling thunderstorm plumes on Earth. Some fraction of these objects are dispersed outwards to cooler regions before being downdrafted again to their destruction. While the theory is adequate to explain some properties of these unique meteorites, it is clear that deeply puzzling aspects remain unexplained. \square

PLANETARY RINGS

J.N. Cuzzi, I. Mosqueira, M. Showalter, F. Poulet

In addition to the natural curiosity inspired by their exotic appearance, planetary rings present a unique dynamical laboratory for understanding the properties of collisional particle disks which might help us understand the accretion of the planets. Ames scientists are involved in a number of different aspects of planetary ring studies.

An ongoing Hubble Space Telescope (HST) program to observe the rings while they "open up" as seen from Earth over the last five years (see Figure 14) has produced over 100 images in a variety of filters. Analysis of these images using a newly developed surface scattering code has led us to the conclusion that the increasing redness of the rings which we found occurs as the angle between the Sun and Earth increases, is caused by unusually rough surfaces on the ring particles. This supports the concept that a ring "particle" is actually an ensemble or aggregation of smaller "particles" - a lumpy snowman-like of fractal structure. Further analysis will help us gain insight into how this structure varies across the rings, on scales that can never be observed directly (tens of meters or less). In addition, this modeling and analysis has established that the abrupt brightening of the rings as the Sun-ring-Earth angle gets very small, which has been previously ascribed to the disappearance of shadows, is more likely due to optical interference effects within the grainy surface of individual particles. This result helps us reconcile the brightening with dynamical expectations that the ring particles are collapsed into a fairly thin, dense layer due to inelastic collisions rather than being many particles thick as had been previously thought. We also hunted down a discrepancy between Voyager and HST color observations of the rings, tracing it to an incorrect Voyager calibration. We can now compare Voyager and HST color data directly, and find that the two data sets are in very good agreement from the standpoint of spatial color variations. We find that variations of color, which trace out particle compositional variations, vary with radius and ring opacity in a way that is quite unusual and will be addressed in future analysis.

The systems of large (and small) regular moons that orbit the gas giant outer planets have always been cited as "solar systems in miniature" but their own origin has remained a puzzle. One recent area of interest is the two outer Galilean moons of Jupiter (Ganymede and Callisto), which are of very similar mass and size, yet have very different internal structure. We have developed a two-stage accretion scenario, which postulates a long-lived, secondary accretion stage only for Callisto involving debris which forms in a very extended disk of material extending far out beyond the boundaries of the current satellite system. A small amount of gas remaining in this disk causes solid material to drift slowly inwards onto the outermost moon, accreting without providing much heating. In addition, a study of the thermal internal evolution of a realistic Callisto was carried out, including ice phase change boundaries and plastic ice convection, showing that a sufficiently slow accretion rate would indeed preclude melting of the icy component and prevent complete differentiation of the icy and rocky material.

Ames maintains the Planetary Data System's Rings Node (http://ringmaster.arc.nasa.gov/), which archives and distributes ring data from NASA's spacecraft missions and from Earth-based observatories. We now have on line the entire archive of images from the Voyager missions to the giant planets, with catalogs to help users find the images they need. We have also produced interactive search and geometrical visualization utilities to assist Cassini scientists in planning observations of the rings during the upcoming tour (2004-2008). Ames also provides the Cassini project with the Interdisciplinary Scientist for Rings and Dust, who chaired the Rings Discipline Working Group this year as it worked through initial ring science sequence planning. \square



Figure 14: HST observations of Saturn since 1996, during which time the ring opening angle has increased from about 4 degrees to about 24 degrees. Data of this quality is available to us in over eight color filters. Voyager data is of higher spatial resolution, but only three filters are available - fortunately they are nearly identical to three of the HST filters.

VORTEX EVOLUTION IN A PROTOPLANETARY DISK

Sanford Davis

The theory that planets form from a thin disk of dust and gas was first proposed in the 18th Century and is now a generally accepted fact. The process by which planets actually emerge from this tenuous state is a subject of intense current study. Recent research points to vortex motion as a possible intermediary where dust particles are captured, concentrated, and finally accumulated by gravitational attraction. These mass accumulations gradually grow to kilometer-sized objects (planetesimals) and ultimately to full-sized planets. Assuming that the disk can support a turbulent flow, it was shown that vortices arise naturally and persist as long as turbulent energy is present. Other possibilities are that vortices arise from certain instabilities in the rotating disk or from external impacts of clumpy infalling gas. In either case, coherent vortices could lead to important and far-reaching processes in the protoplanetary disk.

A research study is underway to determine the effect of vortices on the wave structure in a typical disk which may also play a role in the planet-formation process. It is well known that discrete vortices in a sheared flow do not retain their coherence. This coherence time depends on the local shear rate, the strength, and the size of the vortex. During the shearing epoch, and depending on the nature of the medium, a vortex can emit a variety of wave systems. In this study, the equations of motion have been simulated using a high-resolution numerical method to track Rossby and acoustic/shock waves. Rossby waves are slowly moving waves of vorticity generated in flows with large-scale vorticity gradients. Acoustic waves are waves of expansion and contraction that occur in all compressible media. The protoplanetary disk is a rotating compressible gas with a radially variable rotation rate. It can support both wave systems.

A typical result from the simulation is shown in Figure 15. It is a sequence of snapshots of the perturbed vorticity defined as the difference between the total vorticity and the baseline flow. This baseline flow is a Keplerian flow (rotational velocity = const x (radius) $^{-1/2}$) and the initial vortex is shown in the third quadrant in Figure 15(a). The vortex becomes elongated about its initial location at r=4 (blue-red streaks on the white circle in Figure 15(b)) and both inward and outward-bound counterclockwise spiral vorticity waves are spawned. The outward-bound waves evolve to an axisymmetric wave pattern ("circularization") with shock waves (Figure 15(d)). It is interesting that the vortex-induced waves can induce a supersonic radial flow. Another wave system (Rossby waves) appears in the region r < 10. The shock waves are axisymmetric while the Rossby waves have a cosine angular dependence. Each wave system has a characteristic radial speed.

In follow-up work we will augment the numerical simulations with particle and/or granular gas models to examine the effect of these vorticity-induced waves on particle migration, accumulation, and (possibly) planetesimal formation. \Box

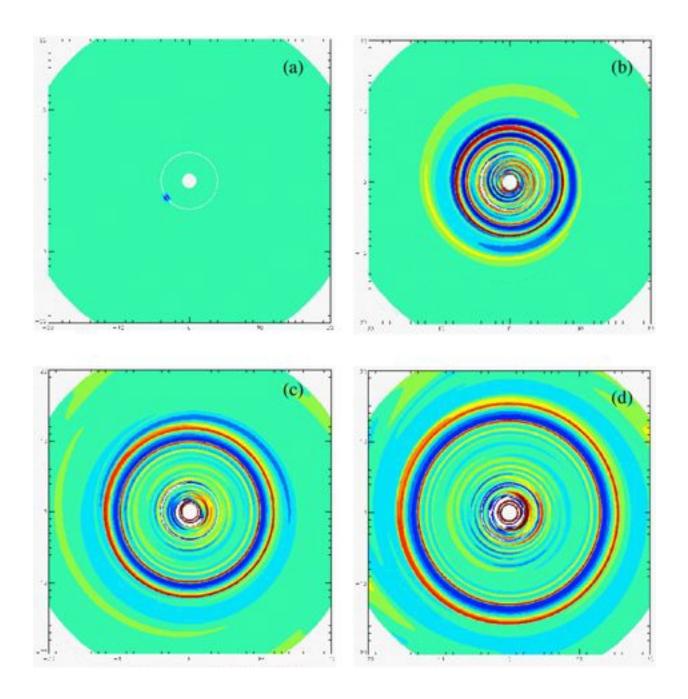


Figure 15: Perturbation vorticity bitmaps showing density (shocks) and Rossby waves. (a)-(d): 0, 16, 32, and 48 vortex revolutions respectively.

LIQUID WATER ON PRESENT DAY MARS?

Robert M. Haberle

Near surface environmental conditions on Mars today are generally considered inadequate to permit liquid water to exist in equilibrium with the atmosphere. Mean annual temperatures are about 50-60 K below the melting point, and mean annual surface pressures are very close to the triple point. Yet there are localized regions where for a few hours out of the day at the right time of year surface temperatures and pressures meet the minimum requirements for the existence of liquid water: pressures and temperatures above the triple point of water, but below the boiling point

That such conditions do in fact exist was determined using a validated General Circulation Model. The model predicts where and for how long liquid water could exist each Martian year. For pure liquid water the model predicts that there are five regions where liquid water might occur: between 0° and 30° N in the plains of Amazonis, Arabia, and Elysium; and in the Southern Hemisphere impact basins of Hellas and Argyre. The combined area of these regions represents 29% of the planet's surface area. In the Amazonis region, these requirements are satisfied for a total integrated time of 37 sols each Martian year. In the Hellas basin, the number of degree-days above zero is 70, which is well above those experienced in the dry valley lake region of Antarctica.

Whether liquid water ever forms in these regions depends on the availability of ice and heat, and on the evaporation rate. The latter is poorly understood for low-pressure CO_2 environments, but is likely to be so high that melting occurs rarely, if at all. However, even rare events of liquid water formation would be significant since they would dominate the chemistry of the soil, and would have biological implications as well.

Interestingly, these regions are remarkably well correlated with the location of impact craters that appear to have been filled with lakes at some time in the past. Approximately 86% of the more than 100 impact crater lakes lie within the model-predicted regions where conditions for liquid water are favorable. The lakes do not exist today, but appear to have existed within the last several billion years, and some appear to have existed within the last several hundred million years. The reason for this amazing correlation is not known. \square

THE CENTER FOR STAR FORMATION STUDIES

D. Hollenbach, K.R. Bell, and G. Laughlin

The Center for Star Formation Studies, a consortium of scientists from the Space Science Division at Ames and the Astronomy Departments of the University of California at Berkeley and Santa Cruz, conducts a coordinated program of theoretical research on star and planet formation. The Center, under the directorship of D. Hollenbach (NASA Ames), supports postdoctoral fellows, senior visitors,

and students, meets regularly at Ames to exchange ideas and to present informal seminars on current research, hosts visits of outside scientists, and conducts a week-long workshop on selected aspects of star and planet formation each summer.

In June 2000 the Center worked together with researchers from the Arcetri Observatory (Florence, Italy) to hold an international workshop entitled "High Mass Star Formation: An Origin in Clusters" The weeklong workshop, held in Volterra, Italy, had approximately 175 attendees, and included an invited talk by D. Hollenbach on "Star Formation and the Fluctuating Ultraviolet Field in the Galaxy."

One focus of the NASA Ames portion of the research work in the Center in 2000 involved the effect of ultraviolet radiation from young massive stars on the interstellar medium of a galaxy. The interstellar medium of a galaxy is the gas and dust which lie between the stars. Most of the gas is hydrogen; the dust mass is only about 1% of the gas mass. The gas and dust reside in various components, often characterized by the gas density in the component. The densest and coldest component is the molecular clouds; this component forms stars..Diffuse clouds are less dense than molecular clouds, they are primarily cold atomic hydrogen. The warm medium consists of neutral and ionized gas at very low density and relatively high temperature. The star formation rate in a galaxy depends on the rate at which molecular clouds can be formed, since only this component forms stars. The molecular clouds are thought to form by the coalescence of diffuse clouds into opaque, self-gravitating clouds. However, high rates of star formation leads to high populations of massive stars which radiate copious ultraviolet flux. The ultraviolet flux in turn heats up the diffuse clouds in the interstellar medium and transforms them into warm medium. Since warm medium is unlikely to form molecular clouds, the lack of diffuse clouds cuts off the supply of molecular clouds in a galaxy which cuts off the star formation rate. This then provides a self-regulation mechanism which controls the rate of star formation in a galaxy.

Another focus of the Ames portion of the Center research in 2000 involved a collaborative theoretical study of the conditions which determine whether a collapsing molecular cloud core of gas and dust gives rise to a single star surrounded by planets or to a binary star system. This work focused on the realization that the molecular cloud cores that precede star formation can have equilibrium configurations that are non-axisymmetric (lopsided). An analytical study carried out by the Center reported on the discovery and the properties of a sequence of these unusual egg-shaped equilibrium configurations. The analysis shows that these configurations can collapse in a way that may naturally produce either binary or single stars, depending on the initial degree of distortion.

The theoretical models of the Center have been used to interpret observational data from such NASA facilities as the Infrared Telescope Facility (IRTF), the Infrared Astronomical Observatory (IRAS), the Hubble Space Telescope (HST), and the Infrared Space Observatory (ISO, a European space telescope with NASA collaboration), as well as from numerous ground-based radio and optical telescopes. In addition, they have been used to determine requirements on future missions such as the Stratospheric Observatory for Infrared Astronomy (SOFIA) and the Space Infrared Telescope Facility (SIRTF). \Box

THE FORMATION AND DYNAMICS OF PLANETARY SYSTEMS

Gregory Laughlin

In the past year, progress was made in a number of areas bearing on the overall problem of planetary systems formation and evolution. Specific topics of research have ranged from the earliest stages of star formation through the long term fate of the Earth, and are described in four peer-reviewed research papers.

In the present-day solar system, the sun contains 99.9% of the mass, whereas the planets contain the bulk of the system angular momentum. The clouds of gas and dust which collapse to form star-planet systems, however, are essentially in uniform rotation. One of the major unsolved puzzles in the theory of star and planet formation thus involves the detailed mechanism by which mass is transported inwards onto the protostar while angular momentum is simultaneously pushed outwards. It is believed that spiral gravitational instabilities play a key role in eliciting angular momentum transport, but a full description of how spirals grow and operate on a global scale (i.e. throughout the entire protoplanetary disk) is not understood. Considerable theoretical progress was made in this area by performing a stability analysis of idealized singular isothermal disks. This research, carried out and published in collaboration with researchers at UC Berkeley, Arcetri (Italy), and UNAM (Mexico), has clearly explained the role of the co-rotation amplifier in allowing spiral waves to grow. This in turn gives us a clearer theoretical picture of the very earliest stages of star and planet formation.

A second line of inquiry has developed a way to constrain the conditions under which our own solar system formed. The outer giant planets in our solar system all have nearly coplanar, circular orbits. This orderly configuration indicates that the Sun and the planets have always existed in relative isolation. Had another stellar system passed within several hundred astronomical units of the Sun, gravitational perturbations would have scattered the outer planets (particularly Neptune) into highly eccentric, inclined orbits. An extensive set of Monte-Carlo star-planet scattering calculations has shown that the solar system likely formed in an aggregate containing fewer than 1500 stars, and thus was not born in a dense stellar cluster (resembling, say, the Trapezium region in Orion). Primitive meteorites, however, contain daughter products of extinct radioactive elements which have half lifes of one million years or less. In order to explain the presence of such short-lived isotopes in meteorites, it has been proposed that either (1) the pre-solar nebula was enriched by a nearby supernova explosion, or alternately that (2) X-ray flares associated with the nascent sun were able to create radioactive atoms via processes such as spallation. The new research strongly favors scenario (2), since the presence of a nearby supernova would imply that the sun formed in a very massive aggregate of stars, and this possibility is effectively ruled out by the Monte-Çarlo calculations.

A third focus of the research effort examined the emerging correlation between high stellar metallicity and the detected presence of an extrasolar planet. Now that more than 70 extrasolar planets have been

found, it is possible to evaluate the emergence of statistical trends. An analysis of volume-limited samples of stars in the solar neighborhood demonstrated that stars with metal content >50% higher than solar are 10 times more likely to harbor a short-period planet than the average star in the solar neighborhood. This finding can be exploited to find extrasolar planets with less effort, thus saving large amounts of time on instruments such as the Keck Telescope. A catalog of 200 highly metal-rich stars was compiled, and within 6 months, 5 planets have been detected in this catalog. Two were found by the Marcy group, two were found by Swiss researchers, and one was found by Ames researchers (HD 20675b, to be confirmed and announced in Fall, 2001).

STABILITY OF UPSILON ANDROMEDAE'S PLANETARY SYSTEM

Jack J. Lissauer, Eugenio Rivera

The objectives of this project are to study the dynamical properties of planetary systems that are consistent with the observational data on the three-planet system orbiting the nearby main sequence star Upsilon Andromedae. We find that systems with the planetary masses and orbital parameters that provide the best fit to stellar radial velocity observations made at Lick observatory through either February 2000 or July 2000 are substantially more stable than systems with the parameters originally announced in April 1999. Simulations using the February 2000 parameters are stable for planetary masses as much as four times as large as the observational lower bounds (which are obtained by assuming that the Solar System lies in the orbital plane of the Upsilon Andromedae planetary system). In relatively stable systems, test particles (which can be thought of as representing asteroids or Earthlike planets that are too small to have been detected to date) can survive for long times between the inner and middle planets as well as several astronomical units or more exterior to the outer planet, but we could find no stable orbits between the middle and outer planets. \Box

THE ORGANIC REFRACTORY MATERIAL IN THE DIFFUSE INTERSTELLAR MEDIUM: MID-IR SPECTROSCOPIC CONSTRAINTS

Yvonne J. Pendleton and Louis J. Allamandola

Through an analysis of the 4000 to 1000 cm $^{-1}$ (2.5 to 10 micron) region of the spectrum of diffuse interstellar medium (DISM) dust compared with the spectra of thirteen laboratory produced chemical candidates which serve as analogs to the interstellar material, we have found that the organic refractory material in the diffuse interstellar medium is predominantly hydrocarbon in nature, possessing little nitrogen or oxygen, with the carbon distributed between the aromatic and aliphatic forms. Long alkane chains H_3C -(CH_2) $_n$ - with n much greater than 4 or 5 are not major constituents of this material.

Spectral analysis of the DISM allows us to place significant constraints on the likelihood of the proposed materials to be present in the diffuse interstellar medium. The spectra of candidate materials are

evaluated using four spectral characteristics based on the interstellar data. Comparisons to laboratory analogs indicate the DISM organic material resembles plasma processed pure hydrocarbon residues much more so than energetically processed ice residues, which were previously thought to be relevant analogs. This result is consistent with a birth site for the carrier of the 3.4 micron band in the outflow region of evolved carbon stars, rather than in the icy mantles of dense cloud dust.

The organic signatures of extragalactic dust, carbonaceous chondritic material, and E. coli bacteria have also been compared because these have been discussed in the literature as relevant to the diffuse interstellar medium. The organic material extracted from the Murchison carbonaceous meteorite and the spectrum of E. coli bacteria reveal spectral features in the 5-10 micron region that are absent in the DISM. Although the presence of unaltered circumstellar components in the Murchison meteorite has been established through several lines of evidence, it is unclear whether or not the aliphatic component which gives rise to the 3.4 micron band is in that category. Considering the complete 2-10 micron wavelength region, there is no spectral evidence for a biological origin of the 3.4 micron interstellar absorption band. The similarity of the aliphatic CH stretch region of dust from our own galaxy compared with that of distant galaxies suggests that the organic component of the ISM is widespread and may be an important universal reservoir of prebiotic organic carbon. \Box

CRATERING RATES ON SYNCHRONOUSLY ROTATING SATELLITES

Kevin Zahnle and Paul Schenk

Impact cratering of synchronously-rotating satellites is expected to occur faster on the leading hemisphere than on the trailing hemisphere. This occurs because the satellite's orbital velocity around the planet is generally large compared to the space velocities of comets and asteroids. The relationship between comets and moons is broadly akin to that between flies and windshields. As it is with cars, the predicted asymmetry is large, with cratering rates at the apex of motion (the center of the leading hemisphere) typically 30-80 times greater than at the antapex. However, the expected asymmetry is at best poorly expressed on actual satellites, with the alarming exception of Triton, where the observed asymmetry is apparently too great. The failure to observe the seemingly inevitable suggests that some of these satellites have led, and may still be leading, interesting lives.

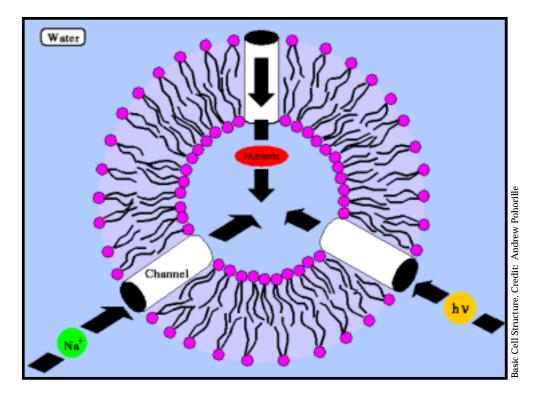
This study used a suite of Monte Carlo simulations to better determine how cratering rates vary across the surfaces of synchronous satellites. The method generates orbits randomly from ancestral distributions that arguably are isotropic, or nearly so; assign to each orbit an impact probability and to each a possible impact site and appropriate crater diameter; while also allowing practical treatment of many effects that would be dauntingly difficult to treat analytically. An empirical fit to the suite of numerical experiments is that the cratering rate $2.0+0.47\gamma$

$$\dot{N} \propto \left(1 + \frac{v_{\text{orb}}}{\sqrt{2v_{\text{orb}}^2 + v_{\infty}^2}} \cos \beta\right)^{2.676477}$$

where V_{orb} refers to the circular orbital velocity of the satellite and V_{∞} refers to the characteristic encounter velocity of the ecliptic comet with the planet; the angle β is the angular distance measured from the apex of motion; and the parameter g is the power law exponent describing the assumed cumulative size distribution of the impactors, $N(>d) < d^{-\gamma}$, where d is diameter. The expression works well for $1 < \gamma < 4$; real solar system populations typically have $1.5 < \gamma < 3$.

As noted above, the predicted cratering asymmetries are not seen in fact. Most synchronous satellites are effectively saturated with impact craters, for which no signature of a leading/trailing cratering asymmetry is to be expected. The three interesting exceptions are Ganymede and Europa, moons of Jupiter, and Triton, chief moon of Neptune. Europa has few impact craters and no obvious leading/trailing asymmetry. But this is not surprising, because Europa's icy shell is decoupled from the interior by a liquid water ocean: it would be relatively easy for the shell to rotate nonsynchronously. Ganymede is a more interesting case. Careful analysis reveals that Ganymede does preserve a fourfold asymmetry between fore and aft. This is much less than the 60-fold asymmetry expected but in the right direction; a possible interpretation is that Ganymede once rotated nonsynchronously but does so no longer. This in turn implicates a once thicker liquid water ocean for Ganymede, a conclusion in harmony with other clues that Ganymede was once much more like Europa than it is now.

Finally, there is Triton. Triton revolves in a retrograde orbit around Neptune. It appears to be a captured comet that melted as its orbit tidally evolved from a highly eccentric ellipse to a circle. Triton has very few craters. Its surface is obviously geologically young, probably no older than Europa's. Essentially all of its impact craters are on its leading hemisphere. In particular, a lack of craters near β =90° appears to be real, as this region (facing Neptune) was the part of Triton seen best by the Voyager 2 spacecraft. This cratering pattern is too asymmetric to be accounted for by comets or other objects that orbit the sun. Required rather are objects in prograde orbit around Neptune. Such objects would strike Triton mostly head-on, and the resulting craters would be mostly confined to the leading hemisphere. The origin of the implied swarm of prograde, Neptune-orbiting debris is an open question. The alternative explanation is that Triton has been capriciously resurfaced so as to look to us, from the one viewpoint of the Voyager 2, as if it had run face-first into a swarm of debris. \Box



Exobiology Branch (SSX) Overview

The Branch's research focuses on the advancement of the scientific understanding of the origin and distribution of life by conducting research on the cosmic history of biogenic compounds, prebiotic evolution, and the early evolution of life. This is accomplished via laboratory experiments, theoretical studies/computational modeling, and field investigations. Branch personnel are also involved in the development of flight instruments, experiments, and small mission definition with particular emphasis being placed on studies of Mars and the development of instrumentation for martian flight missions. Several Branch scientists are part of a task module that is a component of the Ames membership in the Astrobiology Institute. Branch scientists provide expertise in exobiology, astrobiology, planetary protection, and other areas of planetary science to NASA Headquarters and external review and advisory panels, and some serve as editors and associate editors of scientific journals.

Exobiology studies includes the history, distribution, and chemistry of biogenic elements in the solar system; prebiotic chemical evolution and the origin of life; and the history of Earth's early biosphere as recorded in microorganisms and ancient rocks. The research is conducted both on Earth and in space. The Branch also serves as the center of expertise within the agency for issues of planetary protection. As the agency lead center in exobiology, Branch exobiologists exercise a leadership role in NASA's Exobiology Program through program planning, performance reviews, advisory services to related NASA programs, and external relations.

David F. Blake

Chief, Exobiology Branch (SSX)

A GREENHOUSE COLLABORATORY

Brad Bebout and Richard Keller

The Ames Microbial Ecology/Biogeochemistry Research Lab, in combination with the ScienceDesk team, has made significant progress in realizing a greenhouse "collaboratory" which will be shared by members of the NASA Astrobiology Institute's Early Microbial Ecosystems Research Group (EMERG). The greenhouse facility is being used to maintain field-collected microbial mats, as well as perform manipulations of these mats. Microbial mats, extant representatives of Earth's earliest ecosystems, are highly dynamic communities of microorganisms exhibiting extremely high rates of metabolic processes. Maintaining the structure and function of these communities outside of the natural environment is therefore a challenge. Using the greenhouse constructed on the roof of building N239, mats that resemble naturally occurring communities have been maintained over a year after field collection. This year, it was determined that the greenhouse-maintained mats sustain natural rates of biogeochemical processes. This facility, therefore, is useful to support continued measurements of the rates and conditions under which various trace gases are emitted and/or consumed by microbial mats and stromatolites. The greenhouse mats will be used to investigate the effects of early Earth environmental conditions on the rates of trace gas production and consumption in the microbial mats, a period of Earth's history no longer available to us for direct measurement. These measurements are also relevant to the search for life on extrasolar planets, where the most promising search strategy involves the detection of possibly biogenic gases using infrared spectrometry. Space-based interferometers, such as the Terrestrial Planet Finder, should be able to resolve the spectra of several biologically important trace gases in the atmospheres of extrasolar planets, possibly within 10-15 years.

The greenhouse represents a unique facility and a unique resource to be shared among EMERG team members. The team's scientific objectives require multiple collaborators to conduct and analyze measurements of mat parameters on a frequent basis over many weeks. However, pragmatics and funding constraints inhibit the productivity of the distributed team and prevent full utilization of the greenhouse. The construction of a collaboratory – in which human scientists and intelligent agents work together to perform experiments – will alleviate demanding proximity and time requirements that effect productivity. Rather than placing the burden solely on local team members, a collaboratory will enable an entire distributed investigator team to share responsibility for experimentation and data collection.

With this motivation in mind, we have begun construction of a collaboratory designed to enable the geographically distributed group of EMERG scientists to plan greenhouse experiments, operate scientific equipment, take experimental measurements, share results, and collaborate in real time with remote colleagues. Intelligent software agents will assist in the experimentation process, controlling the hardware, recording results, and interacting with the scientists via email. As part of the initial hardware development for the collaboratory, an X,Y,Z positioning table which is capable of

automatically positioning sophisticated instruments at any location in the mats has been constructed. The instrument package currently includes microelectrodes, a light sensor, chlorophyll fluorometer, a surface detection device, and a fiber optic spectrometer. The positioning system, and the instrumentation package is viewable over the internet (http://greenhouse.arc.nasa.gov) via a webcam hooked up to a computer located in the greenhouse. Next implementation steps involve controlling the positioning table and equipment remotely over the internet. \Box

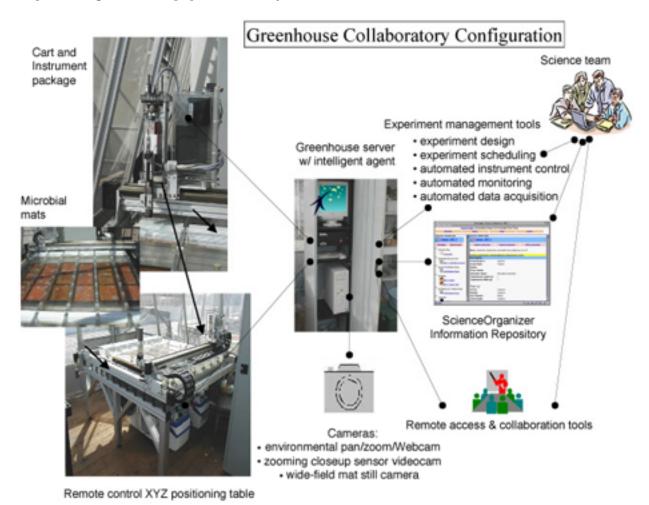


Figure 16: Diagrammatic representation of the greenhouse collaboratory with photographs of the hardware already in place.

CHEMIN: A MINERALOGICAL INSTRUMENT FOR MARS EXPLORATION

David F. Blake

The identification of the types of rocks on Mars that may harbor evidence of present or past life (i.e., biomarkers) will require *in situ* mineralogical analysis. In order to establish the conditions under which a rock formed, the identity of each mineral present and its amount must be determined. In terrestrial laboratories, X-ray Diffraction and X-ray Fluorescence (XRD/XRF) are the techniques of choice for such characterizations.

Recent progress in X-ray technology allows the consideration of simultaneous X-ray diffraction (XRD: mineralogic analysis) and high-precision X-ray fluorescence (XRF: chemical analysis) in systems scaled down in size and power to the point where they can be mounted on landers or small robotic rovers. The CHEMIN XRD/XRF instrument, which simultaneously collects XRD and XRF data, has been proposed in the past for a variety of solar system missions and is presently proposed for three separate Mars scout missions, including a precision lander, a penetrator and a lander equipped with a drill.

NASA was awarded a patent in 1996 (US Patent No. 5,491,738) for the CHEMIN concept. The instrument received a commercial "R&D 100 award" as one of the top 100 innovative technologies of 1998. A SBIR (Small Business, Innovative Research) phase II proposal has been awarded to Moxtek, Inc. to build and commercialize a laboratory version of CHEMIN.

CHEMIN is a CCD-based simultaneous X-ray diffraction / X-ray fluorescence instrument. The device is designed to characterize the elemental composition and mineralogy of small fine-grained or powder samples. The name CHEMIN refers to the instrument's combined CHEmical and MINeralogic capability.

Both diffraction and fluorescence data are obtained simultaneously by operating the CCD in single-photon counting mode. Energy discrimination is used to distinguish between diffracted primary beam photons and fluorescence photons. Diffraction data are obtained in transmission mode, and resolution is presently sufficient on the prototype instrument to allow application of the Rietveld refinement method to the diffraction data. X-ray fluorescence data will be obtained for all elements, 4 < Z < 92.

A diagram of the proposed CHEMIN flight instrument is shown in Figure 17. In operation, the carousel of the instrument (which is the only moving part) is rotated to place one of 40 collection grids in a position to receive a soil sample or a sample of drill cuttings from a rock. The carousel is then rotated to place the grid in the analysis position between the X-ray source and CCD. A combination of carousel rotation and 1-2 mm motion along the x-axis allows the entire substrate to be sampled sequentially by the X-ray beam. An intelligent systems program determines the location of sample material suitable for analysis and supervises data collection.

A prototype of the CHEMIN instrument has been operable since July 1996. After optimization of the X-ray source collimation, diffraction data were obtained in the Fall of 1996 of sufficient quality to be used with advanced diffraction data analysis methods such as Rietveld refinement. Various sample handling systems are presently being pursued, and designs have been proposed for terrestrial use in commercial laboratories, in the International Space Station, and in the proposed Mars Sample Return Handling Facility. \square

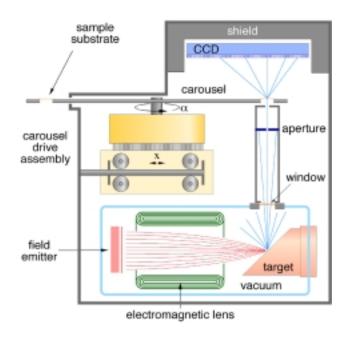


Figure 17: Cross-sectional diagram of the proposed CHEMIN flight instrument.

SUGAR-RELATED COMPOUNDS IN METEORITES

George Cooper, Novelle Kimmich, Josh Sarinana, Katrina Brabham, Laurence Garrel, and Warren Belisle

A goal of NASA is to understand the origin and evolution of life. Carbonaceous meteorites provide the only record yet available for the laboratory study of organic compounds that were synthesized very early in the Solar System and delivered to the planets. Until now sugars and related compounds (polyols), one the most critical classes of compounds necessary for all current lifeforms, had not been definitively identified in extraterrestrial samples. Ribose and deoxyribose, five-carbon sugars, are central to the role of contemporary nucleic acids, DNA and RNA. Glycerol, a three-carbon sugar alcohol, is a constituent of all known biological membranes. Part of the scientific research performed at Ames is directed towards determining if such compounds are part of the organic content of meteorites. This report described the results of the search for such compounds.

Results are reported from analysis of water extracts of the Murchison and Murray carbonaceous meteorites. The means of identification of compounds was gas chromatography-mass spectrometry (GC-MS). Compounds were prepared for GC-MS as their trimethylsilyl and/or tertiary butyl-dimethylsilyl derivatives. Our analyses of Murchison and Murray extracts show that a variety of polyols are present in carbonaceous meteorites (Figure 18). The identified compounds include a sugar, dihydroxy acetone; sugar-alcohols; sugar mono-acids; sugar di-acids; and "deoxy" sugar acids (or "saccharinic" acids). In general the compounds follow the abiotic synthesis pattern of other meteorite classes of organic compounds: decreasing abundance with increasing carbon number within a class of compounds and many, if not all, possible isomers are present at a given carbon number.

A plausible synthetic origin for at least of some of the polyols in Murchison and Murray is the photolysis of interstellar gases on interstellar grains. Another possible origin is the condensation of alkaline aqueous solutions of formaldehyde – which is known to produce polyols. Formaldehyde is a relatively abundant and ubiquitous molecule in interstellar space and comets. Extracts of Murchison and Murray show that the aqueous solution on the parent body(ies) was slightly alkaline. Once produced, further chemistry under alkaline and/or oxidizing can oxidized sugars to a variety of acids of the type in Figure 18.

The fact that a suite of related sugar derivatives and dihydroxyacetone are present in meteorites makes it likely that more sugars were, at one time, also present. Other bodies (comets or asteroids), perhaps in different stages of aqueous alteration or oxidation, may have delivered intact sugars to planets in the early Solar System. However dihydroxyacetone alone is capable of producing larger sugars in aqueous solution. The finding of these compounds in some of the oldest objects in the Solar System suggests that polyhdroxylated compounds were, at the very least, available for incorporation into the first living organisms. \square

	Sugars	Sugar alcohols	Sugar acids	Dicarboxylic Sugar acids
	CH ₂ OH	CH ₂ OH	CO₂H	
3C	c=0	н—с— он	н— с— он	
	ĊН₂ОН	CH ₂ OH	CH ₂ OH	
	Dihydroxyacetone	Glycerol	Glyceric Acid	
		CH₂OH	CO₂H	ÇO ₂ H
		н-с-он	н-с-он	н—с—он
4C		н— с —он	н—с—он	но — с —н
		I CH₂OH	CH ₂ OH	CO₂H
		Erythritol and threitol	Erythronic and Threonic acid	Tartaric and mesotartaric acid
		CH ₂ OH	ÇO ₂ H	CO ₂ H
5C		н—¢—он	н-с-он	н—ç—он
		н—ċ— он	н—с—он	н—ç— он
		н—с—он Г	н—¢— он	н—С—он
		CH ₂ OH	CH₂OH	CO ₂ H
		Ribitol + Isomers	Ribonic Acid + Isomers	2,3,4-Trihydroxy pentane dioic Acid
		CH ₂ OH	ÇO₂H	CO₂H
		н — ф—он	н−¢—он	н—ç—он
6C	*	но— с— он	но—ċ— он	н—¢— он
		н—с—он	Н — ċ — ОН	н— <mark>¢</mark> —он
		н — с — он	H — Ċ — OH	н—ç—он
		CH ₂ OH	CH₂OH	l CO₂H
		Glucitol and Isomers	Gluconic Acid and Isomers	Saccharic acid and Isomers

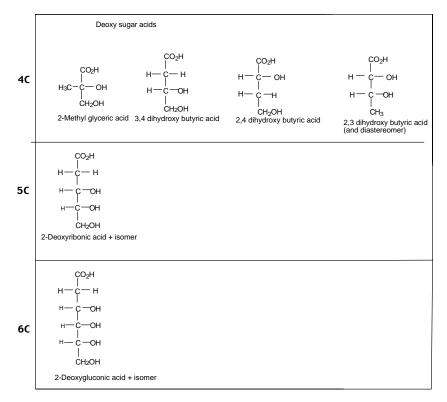


Figure 18: Polyols identified in the Murchison and Murray carbonaceous meteorites. Compounds were identified by gas chromatography-mass spectrometry as their trimethylsilyl and/or tertiary butyl-dimethylsilyl derivatives. *6-C Sugars monomers were not seen but may be present in bound forms.

EFFECTS OF DISTRUBANCE ON MICROBIAL COMMUNITIES

Ken Cullings

This research addresses Astrobiology Objective 14 which deals with ecosystem responses to disturbance. Functional biodiversity results from both absolute species numbers in any ecosystem and interactions among members of the community, and plays a pivotal role in the resilience of ecosystems to disturbance and environmental change. Ecosystem reliability can increase when the number of species per functional group increases, thus illustrating the value of functional redundancy or similarity in an ecosystem. On the other hand, gains or losses of species that perform different functions can cause ecosystem processes to be significantly altered. Thus, a controversial aspect of functional diversity is whether species exhibiting similar function are actually redundant, and thus expendable.

This research targets microbes, and a common view is that the potential for redundancy or similarity among microbial species is high. Specifically, we focus on one pivotal mutualistic interaction, the ectomycorrhizal (EM) symbiosis, a plant/fungal interaction that controls both carbon and nitrogen cycles in forest ecosystems. This research has two steps. First, to assess changes in the EM community in response to disturbance. Second to determine if there are functional changes in the ecosystem that results from any changes.

- 1) Artificial Defoliation (manuscript in press at Oecologia). No previous study has been conducted of effects of altered carbon available to roots in systems comprised of more than a single tree species. Results indicated no significant effect on either EM colonization or on species richness. However, the relative abundance of EM of the two tree species shifted from a ratio of approximately 6:1 without treatment (lodgepole EM:spruce EM), to a near 1:1 ratio post-treatment. In addition, EM species composition changed significantly post-defoliation. Species of EM fungi associating with both lodgepole pine and Engelmann spruce were affected, indicating that alteration of photosynthetic capacity of one species can affect mycorrhizal associations of neighboring non-defoliated trees. Finally, while some fungal species may exhibit consistent specificity patterns (for example Suillus tomentosus to P. contorta) other fungal species shifted host preference in response to the change in source of fixed carbon induced by defoliation.
- 2) Effects of litter addition on a stand of pure lodgepole pine, <u>P. contorta</u>, (data complete, manuscript to be submitted to Oecologia). Molecular analyses indicate that 1) litter addition significantly increases EM infection levels in the top soil layer, directly adjacent to the added litter. No change is seen with perlite addition. Thus, this response is due solely to nutrient changes imposed by litter; 2) the EM community is altered significantly by litter addition. Species dominant in controls may be lost in response following treatment, and some species increase only in response to litter but not to perlite, further illustrating the role of changes in nutrient status.

3) Effects of litter removal on a mixed lodgepoile pine/Engelmann spruce (<u>P. engelmannii</u>) stand (data are complete, manuscript is in preparation): Results of molecular analyses indicate that, 1) litter removal significantly decreased EM fungal species richness, from 3.0 to 1.5 species/core; 2) as expected from previous studies that indicate that increased nitrogen in litter can inhibit EM infection, litter removal induced a significant increase in EM infection, from a mean of 228 EM/core in controls to 326 in treatments; 3) furthermore, molecular analyses indicate that while many basidiomycete fungal species are common to both treatments and controls, the ratio of basidiomycetes to ascomycetes changed significantly in response to litter removal, from 12:1 ratio of basidiomycete to ascomycete EM, to a 3:1 ratio.

Together, these results indicate that these disturbances can causes changes in the EM fungal community. Because different species may perform different functions, these results indicate that it is now necessary to assess changes to pivotal ecosystem functions. Thus, our next step will be to perform assessments of changes in enzyme systems that are responsible for controlling both nitrogen and carbon cycles in forest ecosystems. \square

CARBON NANOTUBE DEPOSITION AND GROWTH TECHNIQUE

Lance Delzeit

Carbon nanotubes (NTs) possess electrical, mechanical and physical properties that make them ideal for applications in nanotechnology. A major constraint to the realization of many of these applications is the ability to produce nanotubes in an industrially viable method with the characteristics desired for the given application. A few of these characteristics include quantity, chirality, size, density, distribution and purity of the nanotubes produced. The research described here focuses on the production of NTs with the desired density, distribution, and purity for the application to industrially viable products.

A catalyst deposition and growth technique has been developed that allows for the controlled growth of either single- or multi-walled carbon nanotubes. This technique uses ion-beam sputtering to deposit the catalyst. By changing the catalyst formula and the growth conditions, either single- or multi-walled carbon nanotubes can be grown. Furthermore, by adjusting the conditions used to produce single-walled nanotubes, the density of the nanotubes grown can be controlled from a sparse distribution of individual single-walled nanotubes to dense mats of single-walled nanotube "ropes". "Ropes" are an association of individual nanotubes that forms a larger structure just as individual fibers make up a normal rope. The conditions for the growth of multi-walled nanotubes have been optimized for the growth of "towers". A "tower" is a structure in which the nanotubes grow in the vertical direction because of the high density of the nanotubes in that region. These different structures each have applications to a variety of devices.

A further advantage of this technique is the ability to pattern the catalyst onto the surface. If the application requires the nanotubes to be grown in a confined area, then the ability to restrict the deposition of the catalyst to those areas is critical. This process, with the use of standard shadow masking and lithography techniques, has the ability to create such patterned catalyst deposits for the development of applications.

Finally, for most applications, the nanotubes need to be produced free of impurities and contamination. The two major sources of contamination in the growth of carbon nanotubes are: 1) the build-up of amorphous carbon from the extraneous decomposition of carbon feed gas and 2) contamination by extraneous metal catalyst. The elimination of the extraneous metal catalyst is currently being accomplished by optimizing the catalyst formula, thus reducing the quantity of "inactive" catalyst. The removal of the amorphous carbon is being realized by the use of etching gases that preferentially removes the amorphous carbon while not damaging the carbon nanotubes. \Box

STRUCTURE AND FUNCTIONS OF PROTOCELLS

Andrew Pohorille and Michael A. Wilson

This research is devoted to the origin of cellular functions, with a long-term objective to explain how protocells performed functions essential for their survival and evolution utilizing only molecules that may have been available in the protobiological milieu. Simple models of several protocellular functions have been developed, and computer simulations have been carried out using molecular dynamics (MD) computer simulations. In MD simulations, Newton's equations of motion are solved for all of the atoms in the system under study, providing a complete time-history of the system. Properties of interest are computed from the trajectory using classical statistical mechanics.

Protocells and their functions: Probably the first cell-like structures were vesicles - closed, spheroidal assemblies of organic material enclosing an aqueous medium. The walls of vesicles are built of amphiphilic molecules which have water-soluble (hydrophilic) and water-insoluble (hydrophobic) groups at opposite ends. These molecules are arranged in bilayers such that the hydrophilic head groups point toward water and the hydrophobic tails form the interior of the bilayer. In this respect, vesicle walls resemble modern cell membranes. Under proper conditions, vesicles form spontaneously from an aqueous solution of amphiphiles. Vesicles became the precursors to true cells - protocells - by acquiring the capabilities needed to survive and reproduce. Protocells had to transport ions and organic matter from the environment across their walls, capture and utilize energy, and synthesize the molecules necessary for self-maintenance and growth. The identity of molecules that performed these functions is open to debate. As most metabolic functions In modern organisms are carried out by proteins, the most parsimonious assumption is that their protobiological precursors were peptides. Their protocellular potential is illuminated by the fact that a wide range of simple, naturally occurring or synthetic peptides can spontaneously insert into membranes and assemble into channels capable of transporting material across cell walls.

Results: The stability of monomers and dimers of a peptide consisting of leucine (L) and serine (S) in a heptad repeat arrangement of (LSLLLSL)₃ has been investigated in a membrane-like system consisting of an octane layer between two water layers. Both the transmembrane and parallel, in-plane orientations of the monomer correspond to stable states, with the parallel orientation being more stable. However conversion between the two requires crossing a large free energy barrier and requires substantial structural rearrangement of the water molecules on both sides of the membrane.

While a transmembrane dimer was found to be stable, a dimer oriented parallel to the interface was found to be unstable. This implies that the predominant state of an equilibrium distribution of peptides is a monomer parallel to the interface. Under the application of an external electric field, the monomers rotate into the transmembrane orientation, where they can aggregation into dimers and tetramers. Experiments in other laboratories have demonstrated that tetramers can function as channels for transporting protons across the membrane.

One goal of this research project is to construct multimeric, transmembrane structures that can function as primitive catalysts. In the present case, the peptide does not possess interactions that are specific enough to maintain a rigid structure that could contain a catalytic site. This is due to the fact that the transmembrane dimer structure, as shown in Figure 19, is much less rigid than a coiled-coil structure. It has been observed more generally that transmembrane proteins are not simply "inside-out" analogues of water soluble proteins. Consequently, specific residues must be modified to achieve the packing that is typical of water-soluble coiled-coils. \square

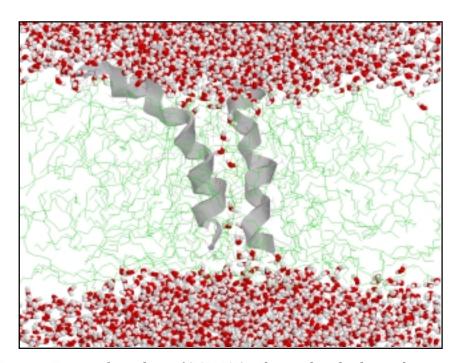


Figure 19: Transmembrane dimer of (LSLLLSL)₃. The peptide molecules are show as gray helices, the octane is green and the water is red and white. The disorder is evidenced by the separation of the helices and the significant water penetration into the membrane interior.

MICROBIAL ECOSYSTEM STRUCTURE

Lee Prufert-Bebout

The Ames Geobiology and Ecosystem Structure Laboratory is a new facility which was initially established in late Summer 2000. The research goals of this laboratory are to contribute to our understanding of the spatial distribution of microbes in biofilms, microbial mats and stromatolites and to understand how these distribution patterns are recorded in the rock record. Spatial distribution of microbes is of critical importance in facilitating the transfer of gaseous and dissolved compounds both between microorganisms and between microorganisms and their environment. As microorganisms are motile and can in effect position themselves where conditions are most advantageous, their distribution patterns offer key clues as to how these ecosystems function. The old adage is that "everything is everywhere, but the milieu selects." Understanding how microbes react to the milieu via their physical distribution is therefore absolutely key to interpreting modern, ancient and extrater-restrial microbial ecosystems.

However, most microbial ecology research approaches are not designed to address this issue. Microbes cultivated as single organism populations in a test tube will not behave in the same manner as those in mixed microbial population assemblages in natural environments. There microbial populations experience fluctuations in irradiance, water flow and chemical environment seldom, if ever, seen in a laboratory environment. Monitoring of natural ecosystems offers clues to as to how ecosystems function, but the large number of variables operating at any given time, prohibit rigorous scientific manipulation and testing. Our goal is to bridge this gap by conducting controlled, mixed microbial ecosystem experimentation.

The first series of experiments in the Geobiology and Ecosystem Structure laboratory has documented that given an initial, homogeneous distribution, within carbonate sediments, four different cyanobacterial isolates will repeatedly segregate themselves with distinctly different distribution patterns. However, the actual distribution patterns observed are a function of speed of water flow, permeability of sediments, availability of nutrients and irradiance conditions. Hence it is possible to control the degree and pattern of lamination occurring in these sediments. The cyanobacteria used in these experiments are cultures isolated from modern stromatolites. This approach provides a powerful tool for interpreting the distribution patterns of these cyanobacteria in their natural environment, which to a great extent causes the formation of the laminated fabric of actively lithifying stromatolites. Some of these microbes act as binding agents holding sediments together, while others are active agents in the precipiation of new mineral components which convert the biological ecosystem into a lithified structure which can be preserved in the rock record. Understanding the controls of formation of these laminated fabrics in modern stromatolites is a first step in improving the interpretation of lamination biosignatures in ancient stromatolites from Earth and potentially laminated rocks from extraterrestrial sources. \Box

RINGDOWN CAVITY FOR ISOTOPIC RATIO MEASUREMENTS OF CARBON AND OXYGEN

Todd Sauke and Joe Becker

Molecular and isotopic spectroscopy in the mid-infrared (3 - 7 micrometer wavelength) has been extremely useful for many quantitative gas detection applications in fields as diverse as astrobiology, geology, atmospheric science, pollution control, environmental monitoring, and industrial process control. Variations in isotopic ratios of $^{12}\text{C}/^{13}\text{C}$ and $^{16}\text{O}/^{18}\text{O}$ in Martian soil samples could be important clues to the planet's geologic and biologic history. Such variations would be expected to be generated in a sample by any process of elemental transfer whose rate limiting step is diffusion controlled. This could include past or present volcanism, freeze thaw cycles, incorporation of carbon dioxide into the soil from the Martian atmosphere, enzymatic reactions, or respiration. Isotopic variability could also be caused in a sample by its having been mixed with other reservoirs of carbon or oxygen.

The typically strong absorption lines in the mid-infrared spectral region allow for sensitive detection without the need for complex, alignment sensitive, multipass sample absorption cells. The diode laser light sources used for spectroscopy in this spectral region typically require cryogenic cooling making them difficult, cumbersome and expensive, limiting their usefulness. On the other hand, in the near-infrared at 1.3 and 1.55 micrometer wavelengths, where inexpensive room temperature laser sources are readily available, the molecular absorption lines are orders of magnitude weaker than those in the mid infrared and can only be used with long path multi-pass absorption cells. Typical long path multi-pass cells, such as White cells, Harriot cells, etc. are large, cumbersome, and alignment sensitive. The relatively new technique of cavity ringdown spectroscopy affords another solution to the problem of achieving very long effective absorption pathlengths.

Laser spectroscopy offers important advantages over conventional mass spectrometry for measurements on a planet's surface. Importantly, because of the high spectral resolution of the laser spectrometer, the detailed and complex sample preparation and purification required for reliable mass spectrometry is unnecessary, because contaminant gasses do not interfere with the measurement. The goal is to develop a prototype instrument for laser spectroscopic isotope analysis of planetary soils and ices on possible missions to Mars and/or Europa.

This project makes use of a ringdown cavity to provide the ultra long effective pathlength needed for spectroscopy with weak infrared absorption lines, but will achieve high light throughput and high spectral resolution by locking the ringdown cavity to the narrow spectral linewidth of a diode laser source.

We have designed and constructed a near-infrared spectrometer consisting of a 1.6 micrometer near-infrared room temperature diode laser, an optical isolator, a spatial filter, and a tuned ringdown cavity which ultimately will be frequency locked to the continuous wave laser source, affording both high spectral resolution of isotopic absorption lines and high optical throughput for high sensitivity measurements. \square

PREBIOTIC PEPTIDE SYNTHESIS

Arthur L. Weber

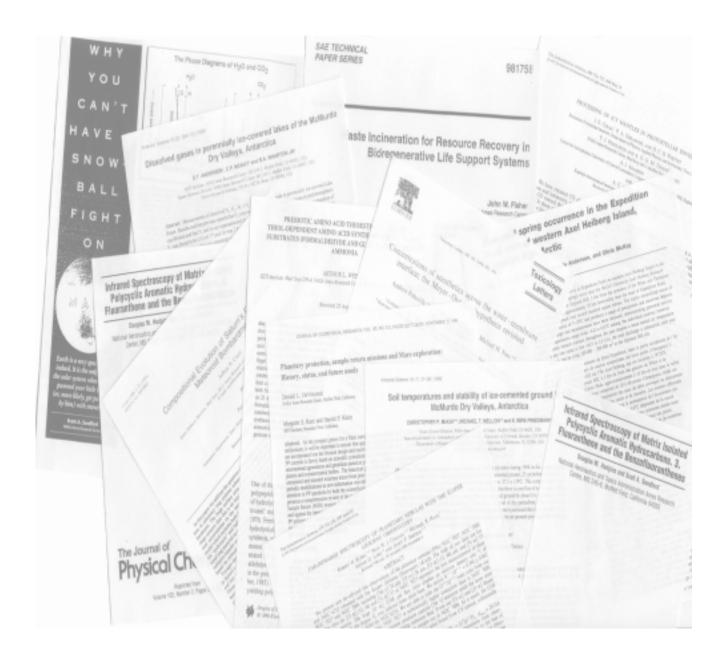
About four billion years ago on the primitive Earth chemical processes yielded molecules that had the ability to make copies of themselves (self-replicate). Over evolutionary time these replicating molecules developed into the DNA-protein replicating system of modern life. Although the DNA molecule has a structure that makes it an excellent self-replicating molecule, DNA's structure is too complex to have been synthesized by chemical processes on the early prebiotic Earth. This difficulty with the prebiotic synthesis DNA has led to a search for simpler replicating molecules. One of the best candidates for a primitive replicating molecule are small proteins – called peptides. Peptides are considered good candidates because they are constructed from very simple building blocks – activated amino acid molecules – that could have been made by chemical processes on the primitive Earth. To understand the prebiotic processes on the early Earth that could have generated replicating molecules, such as peptides, we have (1) experimentally studied plausible prebiotic chemical processes that have the potential to yield peptides and other replicating molecules from very simple chemical ingredients such as formaldehyde and derived sugars, and (2) analyzed the thermodynamics of carbon chemistry to establish which types of organic reactions are energetically favorable or unfavorable under mild aqueous conditions.

Since earlier studies by us and other investigators have indicated the involvement of amino acid and peptide thioesters in prebiotic peptide synthesis, we developed a new, very simple method for preparing peptide thioesters that involves the reaction of a thiol molecule with amino acids activated by reaction with the commercially available reagent (carbonyldiimidazole). This synthetic method was used to prepare peptide thioesters from three and eight amino acids in length for several different amino acids. Chromatographic techniques were developed that allowed measurement and purification of the peptide thioesters. This new synthetic method provides an uncomplicated way to generate peptide thioesters for studies of peptide replication.

To identify and understand the chemistry that could have been involved in the origin of the earliest replicating molecule under mild aqueous conditions, we calculated the energy values for the chemical changes that occur in carbon groups undergoing redox reactions and carbon-carbon bond cleavage reactions. We discovered that the energy of redox reactions involving hydrogen transfer between carbon groups is mainly determined by the type of functional group that donates the hydrogen equivalents, with the energy becoming less favorable in the order: aldehydes, formic acid, alcohols, and hydrocarbons. We also found (1) that the cleavage energy of carbon-carbon bonds is primarily determined by the type of functional group that donates the shared electron-pair during cleavage, with the cleavage energy becoming less favorable in the order: carbonyls (ketones, aldehydes), carboxylic acids, alcohols, hydrocarbons, and (2) that the cleavage energy is more favorable when the shared electron-pair is transferred from a more oxidized to a more reduced carbon group, except for bonds between a carbonyl group and a carboxylic acid group where the reverse transfer is more favorable. From the energy of each cleavage reaction we also estimated the energy of its corresponding synthesis (or reverse) reaction that has an energy equal to the negative of the cleavage energy. From these studies we concluded that the chemistry of the origin of life and the structure of metabolism are constrained and limited by the strong dependence of the energy of carbon group transformations on the type of functional group(s) participating in the transformations. \Box

Space Science Division 2000 Bibliography

The following is a compilation of peer-reviewed publications, with a 2000 publication date, authored by Division personnel. Also included are patents, extended abstracts, chapters in books, etc.



- Adams, F. and Laughlin, G. "Protostellar Disk Formation and Early Evolution," **Space Science Reviews 92(1/2):**23-38 (2000).
- Ashby, M.L.N., E.A. Bergin, R. Plume, J.M. Carpenter, D.A. Neufeld, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, J.E. Howe, S.C. Kleiner, D.G. Koch, B.M. Patten, R. Schieder, R. L. Snell, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, Y.F. Zhang, and G.J. Melnick "An Analysis of Water Line Profiles in Star Formation Regions Observed by the Submillimeter Wave Astronomy Satellite," Astrophys. J. Letters 539:L115 (2000).
- Baines, K. H., G. Bellucci, J.-P. Bibring, R. H. Brown, B. J. Buratti, E. Bussoletti, F. Capaccioni, P. Cerroni, R. N. Clark, A. Coradini, D. P. Cruikshank, P. Drossart, V. Formisano, R. Jaumann, Y. Langevin, D. L. Matson, T. B. McCord, V. Menella, R. M. Nelson, P. D. Nicholson, B. Sicardy, C. Sotin, G. B. Hansen, J. J. Aiello, and S. Amici. "Detection of sub-micron radiation from the surface of Venus by Cassini/VIMS," Icarus 148:307-311 (2000).
- Baldwin, J.A., E.M. Verner, D.A. Verner, G.J. Ferland, P.G. Martin, K.T. Korista, and R.H. Rubin "High-Resolution Spectroscopy of Faint Emission Lines in the Orion Nebula," **Astrophys. J. Supplement 129:**229-246 (2000).
- Beaumont, V.I., Jahnke, L.L. and Des Marais, D.J. "Nitrogen isotopic fractionation in the synthesis of photosynthetic pigments in Rhodobacter capsulatus and Anabaena cylindrica," **Organic Geochemistry 31:**1075-1085 (2000).
- Bell, J.F. III, McSween, H.Y. Jr., Murchie, S.L., Johnson, J.R., Reid, R., Morris, R.V., Anderson, R.C., Bishop, J.L., Bridges, N.T., Britt, D.T., Crisp, J.A., Economou, T., Ghosh, A., Greenwood, J.P., Gunnlaugsson, H.P., Hargraves, R.M., Hviid, S., Knudsen, J.M., Madsen, M.B., Moore, H.J., Rieder, R., and Soderblom, L. "Mineralogic and Compositional Properties of Martian Soil and Dust: Results from Mars Pathfinder," J. Geophys. Res. 105:1721-1755 (2000).
- Bell, K.R., Cassen, P.M., Wasson, J.T., and Woolum, D.S. "FU Orionis Outbursts and Solar Nebula Material" IN **Protostars & Planets IV**, Edited by: V. Mannings, A. Boss, and S. Russell, University of Arizona Press, pp 897-926 (2000).
- Bergin, E.A., E. Lellouch, M. Harwit, M.A. Gurwell, G.J. Melnick, M.L.N. Ashby, G. Chin, N.R. Erickson, P.F. Goldsmith, J.E. Howe, S.C. Kleiner, D.G. Koch, D.A. Neufeld, B.M. Patten, R. Plume, R. Schieder, R.L. Snell, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, and Y.F. Zhang "Submillimeter Wave Astronomy Satellite Observations of Jupiter and Saturn: Detection of 557 GHz Water Emission from the Upper Atmosphere," Astrophys. J. Letters 539:L147 (2000).
- Bergin, E.A., G.J. Melnick, J.R. Stauffer, M.L.N. Ashby, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, J.E. Howe, S.C. Kleiner, D.G. Koch, D.A. Neufeld, B.M. Patten, R. Plume, R. Schieder, R.L. Snell, V. Tolls, Z. Wang, G. Winnewisser, and Y.F. Zhang "Implications of Submillimeter Wave Astronomy Satellite Observations for Interstellar Chemistry and Star Formation," **Astrophys. J. Letters 539**:L129 (2000).

- Bernstein, M.P., Sandford, S.A., Allamandola, L.J., Dworkin, J.P., Gillette, S.J., and Zare, R.N. "Formation of Prebiotic Molecules in Interstellar and Cometary Ices" IN Bioastronomy '99: A new Era in Bioastronomy, Edited by: G. Lemarchand & K. Meech, ASP Conf. Series, 213, pp 197-205 (2000).
- Bernstein, M.P., Sandford, S.A., and Allamandola, L.J. "H, C, N, and O Isotopic Substitution Studies of the 2165 cm-1 (4.62 µm) "XCN" Feature Produced by UV Photolysis of Mixed Molecular Ices," Astrophys. J. 542:894-897 (2000).
- Bernstein, M.P., Sandford, S.A., and Allamandola, L.J. "Molecules from Space and the Origin of Life" IN The Scientific American Book of the Cosmos, Edited by: D. Levi, Byron Preiss Visual Publications, Inc. and Scientific American, pp 265-272 (2000).
- Bishop, J.L. "Identification of secondary minerals on Mars: Importance for water and chemical alteration," AGU Fall Meeting, San Francisco, CA, abs. 4574 (2000).
- Bishop, J.L., Madsen, M.B., Murad, E. and Wagner, P.A. "Identification of Crystalline Minerals in Volcanic Alteration Products and Applications to the Surface of Mars," LPSC XXXI, abs. #1874 (2000).
- Bishop, J.L., Mancinelli, R.L., Madsen, M.B., and Zent, A.P. "Maghemite Formation via Organics and the Prospect for Maghemite as a Biomarker Mineral on Mars," First Astrobiology Science Conf., NASA Ames Research Center, April 3-5 (2000).
- Bishop, J.L., Mancinelli, R.L., Olsen, M., Wagner, P.A. and Zent, A.P. "Ferrihydrite Alteration to Magnetite, Maghemite and Hematite; Implications for Iron Oxides on Mars," LPSC XXXI, abs. #1946 (2000).
- Bishop, J.L. "Mineral identification as an indicator of water and geochemical history on Mars," Concepts and Approaches for Mars Exploration, LPI, Houston, TX. (2000).
- Bishop, J.L. "Mineral identification in palagonitically altered volcanic material as an indicator of geochemical history," Volcano/Ice Interaction on Earth and Mars Conference, Reykjavik, Iceland, August 13-18, 2000, 5 (2000).
- Black, D.C., Kinney A., Allamandola, L.J, Beichman, C., Bodenheimer, P., Cochran, W., Hammel, H., Johnston, K., Mcalister, H., Naderi, F., Neff, S.G., Ruden, S.P., Steidel, C.C., and Stockman, P. "Origins 2000: In Search of Our Cosmic Roots, Origins Theme, Roadmap for NASA's Office Of Space Science," (2000).
- Blake, D.F., P. Weissman, S.A. Collins, P. Sarrazin, D.L. Bish and D. Vaniman "CHEMIN: A Mineralogical Dust Analyzer for the Odyssey Mission to Comet Kopff," Trans. AGU 81(48) (2000).
- Blake, D.F. "Remote X-ray Diffraction and X-ray Fluorescence Analysis on Planetary Surfaces," Advances in X-ray Analysis 43:487-496 (2000).
- Bodenheimer, P., O. Hubickyj, and J.J. Lissauer "Models of the In Situ Formation of Detected Extrasolar Giant Planets," Icarus 143:2-14 (2000).

- Borovicka J. and P. Jenniskens "Time resolved spectroscopy of a Leonid fireball afterglow," **Earth, Moon and Planets 82-83:**399-428 (2000).
- Borucki, W.J., Caldwell, D.A., Jenkins, J.M., Koch, D.G., Showen, R.L. "A Performance Comparison for Two Versions of the Vulcan Photometer," **NASA Conference Publications, CP-2000-209614:**95 (2000).
- Bregman, J.D., Hayward, T.L., and Sloan, G.C. "Discovery of the 11.2 μm PAH Band in Absorption Toward MonR2 IRS3," **Astrophys. J. Letters 544:**L75 (2000).
- Bregman, J.D., Temi, P., and Rank, D. "Direct measurement of the supernova rate in starburst galaxies," **Astron. Astrophys. 355:**525 (2000).
- Bridger, A.F.C., Hollingsworth, J.L., and Banfield, D. "Comparison of Observed and Simulated Stationary and Tidal Waves in Mars' Atmosphere," **Geophys. Res. Abs. 2:**77 (2000).
- Brinton, K.L.F., McDonald, G.D., Dworkin, J.P., Levy, M., Miller, S.L. and Bada, J.L. "The cosmogeochemistry of amino acid synthesis from hydrogen cyanide," **Orig. Life Evol. Bios. 30**:227 (2000).
- Burrows, A., Guillot, T., Hubbard, W.B., Marley, M.S., Saumon, D., Lunine, J.I., and Sudarsky, D. "On the Radii of Close-in Giant Planets," **Astrophys. J. Letters 534:**L97-L100 (2000).
- Burrows, A., Marley, M.S., and Sharp, C.M. "The Near-Infrared and Optical Spectra of Methane Dwarfs and Brown Dwarfs," **Astrophys. J. Letters 531:**438-446 (2000).
- Byrd, K.B., Parker, V.T., Vogler, D.R., and K.W. Cullings "The influence of clear-cutting on ectomycorrhizal fungus diversity in a Lodgepole pine (Pinus contorta) stand, Yellowstone National Park, Wyoming, and Gallatin National Forest, Montana," **Canadian Journal of Botany 78:**149-156 (2000).
- Cabrol, N.A., and E.A. Grin "Assessing the Water Resources of Mars (Inventory and Exploration Means)," **International Symposium of Water, Stars, and Life**, Cannes (France), May 30-June 1 (2000).
- Cabrol, N.A., and E.A. Grin "High-latitude martian impact paleolakes: the possible contribution of snowfall and ancient glaciers in the lacustrine activity associated to Argyre and Hellas," **Polar Conf.** Auig., Iceland (2000).
- Cabrol, N.A., and E.A. Grin "**La Recherche de la Vie dans l'Univers**," Edited by: Presses Universitaires de France Presses Universitaires de France, Paris (France), pp 128 (2000).
- Cabrol, N.A., and E.A. Grin "Lacustrine deltas in martian impact crater lakes: morphologies, types, and significance," **LPSC XXXI** (2000).
- Cabrol, N.A, and E.A. Grin "Recent Lakes on Mars," **First Astrobiology Science Conf.**, NASA Ames Research Center, April 3-5 (2000).
- Cabrol, N.A., and E.A. Grin "The evolution of lacustrine environments on Mars: Is Mars only Hydrologically Dormant?," Icarus 149:291-328 (2000).

- Cabrol, N.A. "Astronaut-Rover exploration strategy (ARES) for the human exploration of Mars," LPSC XXXI (2000).
- Cabrol, N.A., E.A. Grin, and W.H. Pollard "Possible frost mounds in ancient Martian lakebed," Icarus **145:**91-107 (2000).
- Cabrol, N.A., E.A. Grin, R. Haberle, C. McKay, M. Joshi, and J. Schaeffer "Distribution and ages of martian impact crater lakes (I): the morphological evidence for recent lacustrine activity," LPSC XXXI, 1504 (2000).
- Cabrol, N.A., Gian Gabriele Ori, Edmond. A. Grin, Lucia Marinangeli, Christopher McKay, John Marshall, Hans Thomas, Maura Rabette, Mike Sims, Ragnhild Landheim "Mars scout: an astrobiology micromission to investigate martian environments," LPSC XXXI (2000).
- Cabrol, N.A., Gian Gabriele Ori, Edmond. A. Grin, Michael H. Sims, Lucia Marinangeli, Christopher McKay, John Marshall, Hans Thomas, Maura Rabette, and Ragnhild Landheim "Mars scout: micromissions to investigate martian environments.," Workshop for Concept and Approaches for Mars Missions, LPI (2000).
- Caldwell, D.A., W.J. Borucki and J.J. Lissauer "The Vulcan Photometric Search for Transiting Giant Planets: Some Initial Results" IN Bioastronomy '99 A New Era in Bioastronomy, ASP Conference Series 213, Edited by: G.A. Lemarchand and K. Meech, Sheridan: Chelsea, MI, pp 101-106. (2000).
- Calva-Alejo, L., D.N. Mvondo, C.P. McKay, and R. Navarro-Gonzalez "Evidence of a nitrogen deficiency as a selective pressure towards the origin of biological nitrogen fixation on the early Earth" IN Astrobiology, Edited by: J. Chela-Flores, G.A. Lemarchand, and J. Oro, Kluwer Scientific, Dordrecht, The Netherlands (2000).
- Caroff, L.I., and Des Marais, D.J., Eds. "Pale Blue Dot 2 Workshop: Habitable and Inhabited Worlds Beyond Our Solar System," NASA Conference Publications, CP-2000-209595:320 (2000).
- Castellano, T. "A Search for Planetary Transits of the Star HD 187123 by Spot Filter CCD Differential Photometry," Astronomical Society of the Pacific 112:821 (2000).
- Castellano, T., J. Jenkins, D. Trilling, L. Doyle, and D. Koch "Detection of Planetary Transits if the Star HD 209458 in the Hipparcos Data Set," Astrophysical Journal 532:L51-L53 (2000).
- Catling, D., and J. Moore "Iron oxide deposition from aqueous solution and iron formations on Mars," LPSC XXXI, #1517 (2000).
- Catling, D.C., C.P. McKay, and K.J. Zahnle "Biogenic methane and the oxidation state of early Earth," Eos Trans. AGU 81(48), Fall Meeting Supplement, F809 (2000).
- Catling, D., C.P. McKay, and K. Zahnle "The timescale to develop oxygen atmospheres on habitable extrasolar planets and the consequences for extraterrestrial life," First Astrobiology Science Conf., NASA Ames Research Center, April 3-5 (2000).

- Ceccarelli, C., Castets, A., Caux, E., Hollenbach, D., Loinard, L., Molinari, S., and Tielens, A.G.G.M. "The structure of the collapsing envelope around the low-mass protostar IRAS 16293-2422," **Astron. Astrophys. 355:**1129-1137 (2000).
- Chambers, J.E., and M.A.Murison "Pseudo-High-Order Symplectic Integrators," **Astron. J. 119**:425-433 (2000).
- Chambers, J.E. "Terrestrial Planet Formation in Extrasolar Systems," **Bulletin of the American Astronomical Society 32**:1050 (2000).
- Chan, K-W., Roellig, T.L., Onaka, T., Mizutani, M., Okumura, K., Yamamura, I., Tanabe, T., Shibai, H., Nakagawa, T., and Okuda, H. "Characterization of the Unidentified Infrared Emission Bands in the Diffuse Interstellar Medium," **ESA Special Publication, SP-456** (2000).
- Chapman, M.G., C.C. Allen, M.T. Gudmundsson, V.C. Gulick, S.P. Jakobsson, B.K.Lucchitta, I.P. Skilling, and R.B. Waitt "Volcanism and Ice Interactions on Earth and Mars" IN **From the Deep Oceans to Deep Space: Environmental Effects on Volcanic Eruptions**, Edited by: Zimbleman, J. and Gregg, T., Kluwer Academic/Plenum Publishers, New York, pp 39-73 (2000).
- Chaput, C., Bloom, E., Cominsky, L., Godfrey, G., Hertz, P., Scargle, J., Shabad, G., Wen, H., Wood, K., and Yentis, D. "A Search for Aperiodic Millisecond Variability in Cygnus X-1," **Astrophys. J. 541:**1026-1032. (2000).
- Charnley, S.B. and Kaufman, M.J. "Carbon Dioxide in Star-forming Regions," **Astrophys. J. Letters 529**:L111 (2000).
- Chiar, J.E., Tielens, A.G.G.M., Whittet, D.C.B., Schutte, W.A., Boogert, A.C.A., Lutz, D., van Dishoeck, E.F., and Bernstein, M.P. "The Composition and Distribution of Dust Along the Line of Sight Towards the Galactic Center," **Astrophys. J. 537**:749-762 (2000).
- Chiar, J.E., Tielens, A.G.G.M., Whittet, D.C.B, Schutte, W.A., Boogert, A.C.A., Lutz, D., van Dishoeck, E.F., and Bernstein, M.P. "The Composition and Distribution of Dust Along the Line of Sight Towards the Galactic Center," **ESA Special Publication**, **SP-456**:45-48 (2000).
- Christensen, P.R., J.L. Bandfield, R.N. Clark, K.S. Edgett, V.E. Hamilton, T. Hoefen, H.H. Kieffer, R.O. Kuzmin, M.D. Lane, M.C. Malin, R.V. Morris, J.C. Pearl, R. Pearson, T.L. Roush, S.W. Ruff, and M.D. Smith "Detection of crystalline hematite mineralization on Mars by the Thermal Emission Spectrometer: Evidence for Near-surface water," J. Geophys. Res.-Planets 105:9623-9642 (2000).
- Cockell, C.S., D.C. Catling, W.L. Davis, K. Snook, R.L. Kepner, P. Lee, and C.P. McKay "The ultraviolet environment of Mars: Biological implications past, present, and future," *Icarus* 146:343-359 (2000).
- Cockell, C.S., N.A. Cabrol, E.A. Grin, and R.M. Haberle "Environmental stress and the search for life on Mars," **First Astrobiology Science Conf.**, NASA Ames Research Center, April 3-5 (2000).

- Cohen, M., Walker, R.G., and F.C. Witteborn "Building a Network of Self-Consistent Mid-IR Calibration Stars" IN **Thermal Emission Spectroscopy of Dust, Disks, and Regoliths**, ASP Conference Series, Edited by: M.L. Sitko, A.L. Sprague, and D.K. Lynch, Astronomical Soc. of the Pacific, San Francisco, Calif., 196, pp 345-356 (2000).
- Colgan, S.W.J., Cotera, A.S., Maloney, P.R., and Hollenbach, D.J. "Infrared Spectroscopy of Black Hole Candidates," **Bulletin of the American Astronomical Society Meeting 196**, #38.04 (2000).
- Cooper, George, Friedrich Hörz, Alanna Oleary, and Sherwood Chang "Shock Modification Of Organic Compounds On Carbonaceous Chondrite Parent Bodies," **LPSC XXXI** (2000).
- Cotera, Angela S., Janet P. Simpson, Edwin F. Erickson, Sean W.J. Colgan, Michael G. Burton, and David A. Allen "Interstellar Extinction in the Vicinity of the Galactic Center," **Astrophysical Journal Supplement Series 129**:123-146 (2000).
- Cotera, Angela S., Sean W.J. Colgan, and Janet P. Simpson "The interaction of the Galactic center Arches Cluster and the Thermal Filaments," **ISO Beyond the Peaks: The 2nd ISO workshop on analytical spectroscopy** (2000).
- Cruikshank, D.P. and B.N. Khare "Planetary Surfaces of Low Albedo: Organic Material Throughout the Solar System" IN **Bioastronomy '99-A New Era in Bioastronomy**, Edited by: G. A. Lemarchand and K. J. Meech, ASP Conf. Series, 213, pp 253-261 (2000).
- Cruikshank, D.P., B. Schmitt, T.L. Roush, T.C. Owen, E. Quirico, T.R. Geballe, C. de Bergh, M.J. Bartholomew, C.M. Dalle Ore, S. Douté, and R. Meier "Water Ice on Triton," Icarus 147:309-316 (2000).
- Cullings, K. "Reassessment of phylogenetic relationships of some members of the Monotropoideae based on partial 28S ribosomal RNA gene sequencing," **Canadian Journal of Botany 78:**1-2 (2000).
- Cullings, K.W., Parker, V.T., Finley, S.K. and D.R. Vogler "Assessment of specificity patterns in a mixed Pinus contorta/Picea engelmannii forest in Yellowstone Park," **Appl. Environ. Microbiol. 66**:4988-4991 (2000).
- Dale, D.A., N.A. Silbermann, G. Helou, E. Valjavec, S. Malhotra, C.A. Beichman, J. Brauher, A. Contursi, H.L. Dinerstein, D.J. Hollenbach, D.A. Hunter, S. Kolhatkar, K-Y. Lo, S.D. Lord, N.Y. Lu, R.H. Rubin, G.J. Stacey, H.A. Thronson, M.W. Werner, and H.G. Corwin "ISO Mid-Infrared Observations of Normal Star-Forming Galaxies: The Key Project Sample," **Astron. J. 120(2):**583-603 (2000).
- Davis, S.S., D.P. Sheehan, and J.N. Cuzzi "On the Persistence of Small Regions of Vorticity in the Protoplanetary Nebula," **Astrophys. J. 545**:494-503 (2000).
- Davis, W.L. "Light transmission through rock: Application to desert ecology," **M.S. Physics Dissertation**, San Francisco State University, San Francisco, CA, 121 (2000).
- Delzeit, L. and D.F. Blake "Characterization of crystalline ice nanoclusters using Transmission Electron Microscopy," **Workshop on Processing of Outer Solar System Ices (PROSSI)**, Johns Hopkins University, APL, Balatimore, MD. (2000).

- Des Marais, D.J. "Nomination of John M. Hayes for the 1998 Alfred E. Treibs Award," **Geochem. Cosmochim Acta 63:**3935-3936 (2000).
- Des Marais, D.J. "When did photosynthesis emerge on Earth?," Science 289:1703-1705 (2000).
- Desch, S. and J.N. Cuzzi "Formation of chondrules by lightning in the protoplanetary nebula," **Icarus 143:87-105** (PPIV special issue) (2000).
- Despois D., Ricaud P., Lautie N., Schneider N., Jacq T., Biver N., Lis D.C., Chamberline R.A., Phillips T.G., Miller M., Jenniskens P. "Search for extraterrestrial origin of atmospheric trace molecules radio submm observations during the Leonids," **Earth, Moon and Planets 82-83:**129-140 (2000).
- Dobrovolskis, A.R. and J.J. Lissauer "The fate of ejecta from Hyperion," **31st Annual Meeting of the Division on Dynamical Astronomy**, Yosemite, CA, 9-12 April, 2000 (2000).
- Doran, P.T., Wharton, R.A., Lyons, W.B., Des Marais, D.J. and Andersen, D.T. "Sedimentology and geochemistry of a perenially ice-covered epishelf lake in Bunder Hills Oasis, East Antarctica," Antarctic Science 12(2):131-140 (2000).
- Dotson, J., Erickson, E.F., Haas, M.R., Rabanus, D., and Baltz, J.A. "A 16 x 24 Germanium photoconductor array for AIRES," **Proceedings of the SPIE, Airborne Telescope Systems, Volume 4014**, held in Munich, Germany in March 2000, 137-147 (2000).
- Dotson, Jessie L., Davidson, Jacqueline, Dowell, C. Darren, Schleuning, David A., and Hildebrand, Roger H. "Far-Infrared Polarimetry of Galactic Clouds from the Kuiper Airborne Observatory," **Astrophys. J. Supplement Series 128(1):**335-370 (2000).
- Dworkin, J.P., and Miller, S.L. "A kinetic estimate of the free aldehyde content of aldoses," **Carbo. Res. 329:**359-365 (2000).
- Dworkin J.P., Deamer, D.W., Sandford, S.A., Allamandola, L.J., Gillette, J.S., and Zare, R.N. "Simulations of Cometary Ice: Large Molecule Synthesis and Self-assembly Properties," **Orig. Life Evol. Biosph. 30**:228-229 (2000).
- Dworkin, J.P., Sandford, S.A., Allamandola, L.J., Deamer, D.W., Gillette, S.J., and Zare, R.N. "Synthesis of Large Molecules in Cometary Ice Analogs: Physical Properties Related to Self-Assembly Processes" IN **Bioastronomy** '99: A new Era in Bioastronomy, Edited by: G. Lemarchand & K. Meech, ASP Conf. Series, 213, pp 195-196 (2000).
- Ennico, K.A. and Greene, T.P. "An Integrated Science Instrument Module for the Next Generation Space Telescope," **Proceedings of Next Generation Space Telescope Science and Technology**, ASP Conference Series, Vol. 207, 127 137. (2000).
- Fanale, F.P., J.C. Granahan, R. Greeley, R. Pappalardo, J. Head III, J. Shirley, R. Carlson, A. Hendrix, J. Moore, T.B. McCord, M. Belton, "Galileo NIMS and SSI Instrument Teams (2000) Tyre and Pwyll: Galileo orbital remote sensing of mineralogy versus morphology at two selected sites on Europa," J. Geophys. Res. 105:22647-22656 (2000).

- Finn, J.E., L.M. Mulloth, and B.A. Borchers "Performance of Adsorption-based CO2 Acquisition Hardware for Mars ISRU," 30th Intl. Conf. on Environ. Systems (ICES) (2000).
- Finn, J.E. "Separation and Conditioning of Mars Atmospheric Gases via TSA," 2000 Annual Meeting of the AIChE, Los Angeles, CA, Nov. 12-17, 2000 (2000).
- Fisher, J.W., S. Pisharody, M.J. Moran, K. Wignarajah, Y. Shi, and S.G. Chang "Reactive Carbon from Life Support Wastes for Incinerator Flue Gas Cleanup," 30th Intl. Conf. on Environ. Systems (ICES) (2000).
- Flynn, M., and B. Borchers "Assessment of the Technical Readiness of the Vapor Phase Catalytic Ammonia Removal Process," 30th Intl. Conf. on Environ. Systems (ICES), SAE Technical Paper No. 2000-01-2287 (2000).
- Flynn, M., J. Hines, and C. McKay "Astrobiology Hydrothermal Vent Technology Development," 30th Intl. Conf. on Environ. Systems (ICES), SAE Technical Paper No.2000-01-2287 (2000).
- Freedman, R.S., Schwenke, D.W. "A preliminary ab-initio calculation of the spectrum of CH4 and its applications to the spectra of giant planets and brown dwarfs," American Astronomical Society, **DPS meeting #32**, Late Abstracts, #65.36 (2000).
- Freedman, R. "The Development of Opacity Databases for Brown Dwarfs and Extra Solar Giant Planets" IN From Giant Planets to Cool Stars, Edited by: Caitlin A. Griffith and Mark S. Marley, ASP Conference Series, San Francisco, 212 (2000).
- Gazis, P.R. "A large-scale survey of corotating interaction regions and their successors in the outer heliosphere," J. Geophys. Res. 105:19 (2000).
- Gibb, E. L., Whittet, D. C. B., Schutte, W. A., Boogert, A. C. A., Chiar, J. E., Ehrenfreund, P., Gerakines, P. A., Keane, J. V., Tielens, A. G. G. M., van Dishoeck, E. F., Kerkhof, O. "An Inventory of Interstellar Ices toward the Embedded Protostar W33A," Astrophys. J. 536:347-356 (2000).
- Goldsmith, P.F., G.J. Melnick, E.A. Bergin, J.E. Howe, R.L. Snell, D.A. Neufeld, M. Harwit, M.L.N. Ashby, B.M. Patten, S.C. Kleiner, R. Plume, J.R. Stauffer, V. Tolls, Z. Wang, Y.F. Zhang, N.R. Erickson, D.G. Koch, R. Schieder, G. Winnewisser, and G. Chin "O2 in Interstellar Molecular Clouds," Astrophys. J. Letters 539:L123 (2000).
- Goorvitch, D. "Calculation of Instrument Functions," Journal of Quantative Spectroscopy and Radiative Transfer 67:253-257 (2000).
- Gorti, U. and D. Hollenbach "Photoevaporation of clumps in Photodissociation Regions," Bulletin of the American Astronomical Society Meeting 197, #59.03 (2000).
- Goukenleuque, Cédric, Bézard, Bruno, Joguet, Benoit, Lellouch, Emmanuel, Freedman, Richard "A Radiative Equilibrium Model of 51 Peg b," Icarus 143:308-323 (2000).

- Greeley, R., P.H. Figueredo, D.A. Williams, F.C. Chuang, J. Klemaszewski, S.D. Kadel, L. Prockter, R. Pappalardo, J.W. Head III, G.C. Collins, N. Spaun, R. Sullivan, J.M. Moore, D. Senske, B.R. Tufts, T.V. Johnson, M.J.S. Belton, and K. Tanaka "Geologic mapping of Europa," J. Geophys. Res. 105:22559-22578 (2000).
- Greene, Thomas P., and Lada, Charles J. "High-Resolution Near-Infrared Spectra of Protostars," **Astron. J. 120**:430 436 (2000).
- Griffith, C.A., and Marley, M.S. "From Giant Planets to Cool Stars" IN **ASPC Conf. Ser. 212: From Giant Planets to Cool Stars**, Astron. Soc. Pacific Conf. Series, San Francisco, 212 (2000).
- Grin, E.A., and N.A. Cabrol "2000. Hydrologic and climatic significance of lacustrine deltas in martian impact crater," **LPSC XXXI**, 1299 (2000).
- Gulick, V.C. and M.T. Gudmundsson, editors "Volcano/Ice Interaction on Earth and Mars Conference, Reykjavik, Iceland, August 13-18, 2000, Edited by: Gulick, V.C. and M.T. Gudmundsson, pp 62 (2000).
- Gulick, V.C., D.G. Deardorff, G.A. Briggs, T.A. Sandstrom, Y. Hung, and K.P. Hand "A Virtual Collaborative Web Environment For Mars Landing Site Studies," **First Astrobiology Science Conf.**, NASA Ames Research Center, April 3-5 (2000).
- Gulick, V.C., D.G. Deardorff, G.A. Briggs, T.A. Sandstrom, Y. Hung, and K.P. Hand "A Virtual Collaborative Web Environment For Mars Landing Site Studies," **LPSC XXXI** (2000).
- Gulick, V.C. "Fluvial valleys and Ocean Formation on Mars: Insights from MGS," LPSC XXXI (2000).
- Gulick, V.C., R.L. Morris, E.B. Bandari, and T.L. Roush "Maximizing Science Return from Future Mars Missions with Onboard Image Analyses," **LPSC XXXI** (2000).
- Gulick, V.C. "The Role of Volcano/Magma H2O Interactions in Valley and Channel Formation on Mars," Volcano/Ice Interaction on Earth and Mars Conference, Reykjavik, Iceland, August 13-18, 2000 (2000).
- Gural, P. and P. Jenniskens "Leonid storm flux analysis from one Leonid MAC Video AL50R," **Earth, Moon and Planets 82-83:**221-247 (2000).
- Gurwell, M.A., E.A. Bergin, G.J. Melnick, M.L.N. Ashby, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, J.E. Howe, S.C. Kleiner, D.G. Koch, D.A. Neufeld, B.M. Patten, R. Plume, R. Schieder, R.L. Snell, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, and Y.F. Zhang "Submillimeter Wave Astronomy Satellite Observations of the Martian Atmosphere: Temperature and Vertical Distribution of Water Vapor," Astrophys. J. Letters 539:L143 (2000).
- Haas, Michael R. "A telescope assembly alignment simulator for SOFIA," **Proceedings of the SPIE, Air-borne Telescope Systems**, Volume 4014, held in Munich, Germany in March 2000, 172 182 (2000).
- Haberle R. M., C. P. McKa,y, J. Schaeffer, M. Joshi, N. A. Cabrol, and E. A. Grin "Meteorological control on the formation of paleolakes on Mars," **LPSC XXXI**, abstract #1509 (2000).

- Halasinski, T., Hudgins, D.M., Salama, F., Allamandola, L.J., and Bally, T. "Electronic Absorption Spectra of Neutral Pentacene (C22H14-) and its Positive and Negative Ions in Ne, Ar, and Kr Matrices," J. Phys. Chem. 104:7484-7491 (2000).
- Hammel, H.B., G.W. Lockwood, K.A. Rages, and M. Marley "Uranus 2000 New Images, New Spectra, and a New Look," **B.A.A.S 32:**1446-1447 (2000).
- Heyenga, A.G., A. Forsman, L.S. Stodieck, A. Hoehn, and M. Kliss "Approaches in the Determination of Plant Nutrient Uptake and Distribution in Space Flight Conditions," **Advan. Space Res. 26(2):**299-302 (2000).
- Heyenga, A.G., M. Kliss, A. Hoehn, and L.S. Stodieck "The Design of a Mechanized Seed Sowing System for Space Flight Application," **30th Intl. Conf. on Environ. Systems (ICES)** (2000).
- Hildebrand, R.H., Davidson, J.A., Dotson, J.L., Dowell, C.D., Novak, G., and Vaillancourt, J.E. "A Primer on Far-Infrared Polarimetry" IN **The Publications of the Astronomical Society of the Pacific 112(775)** (2000).
- Hoehn, A., L.S. Stodieck, J. Clawson, E. Robinson, H. Seelig, A.G. Heyenga, and M. Kliss "Atmosphere Composition Control of Spaceflight Plant Growth Chambers," **30th Intl. Conf. on Environ. Systems (ICES)** (2000).
- Hoehn, A., P. Scovazzo, L.S. Stodieck, J. Clawson, W. Kalinowski, A. Rakow, D. Simmons, A.G. Heyenga, and M. Kliss "Microgravity Root Zone Hydration Systems," **30th Intl. Conf. on Environ. Systems** (ICES) (2000).
- Hollenbach, D.J., Yorke, H.W., and Johnstone, D. "Disk Dispersal around Young Stars" IN **Protostars and Planets IV**, Edited by: V. Mannings, A. Boss, and S. Russell, Tucson: University of Arizona Press, pp 401 (2000).
- Hollingsworth, J.L., Haberle, R.M., and Schaeffer, J. "Modeling Frontal Waves in Mars' Atmosphere," **Geophys. Res. Abs. 2:86** (2000).
- Horner, S.D., Germain, M.E., Greene, T.P., Harris, F.H., Johnson, M.S., Johnston, K.J., Monet, D.G., Murison, M.A., Phillips, J.D., Reasenberg, R.D., Seidelmann, P.K., Urban, S.E., and Vassar, R.H. "The Full-Sky Astrometric Mapping Explorer — Distances and Photometry of 40 Million Stars," Proceedings of The Impact of Large-Scale Surveys on Pulsating Star Research, ASP Conference Series, Vol. 203, 76-77 (2000).
- Houck, J.R., Roellig, T.L., Van Cleve, J., Brandl, B., and Uchida, K. "Fabrication and Testing of the IRS: the Spectrograph on SIRTF," **SPIE Conference Procedings 4131:**70-77 (2000).
- Howe, J.E., Ashby, M.L.N., Bergin, E.A., Chin, G., Erickson, N.R., Goldsmith, P.F., Harwit, M., Hollenbach, D.J., Kaufman, M.J., Kleiner, S.C., Koch, D.G., Neufeld, D.A., Patten, B.M., Plume, R., Schieder, R., Snell, R.L., Stauffer, J.R., Tolls, V., Wang, Z., Winnewisser, G., Zhang, Y.F., and Melnick, G.J. "Extended [C I] and 13CO (5—>4) Emission in M17SW," **Astrophys. J. 539(2):**L137-L141 (2000).

- Hudgins, D.M., Bauschlicher, Jr., C.W., Allamandola, L.J., and Fetzer, J.C. "Infrared Spectroscopy of Matrix-Isolated Polycyclic Aromatic Hydrocarbon Ions 5. PAHs Incorporating a Cyclopentadienyl Ring," J. Phys. Chem. A 104:3655-3669 (2000).
- Jasien, P.G., Miller, S.L., Levy, M., and Dworkin, J.P "How could life have arisen on Earth?" IN **ChemConnections**, Edited by: C. B. Moore, B. Spencer & T. Schwartz, John Wiley & Sons, Inc.: New York (2000).
- Jenkins, Jon M., Fred Witteborn, David G. Koch, Edward Dunham, William J. Borucki, Todd F. Updike, Mark A. Skinner, and Steve P. Jordan "Processing CCD images to detect transits of Earth-sized planets: Maximizing sensitivity while achieving reasonable downlink requirements," SPIE Conference Series, volume 4013, UV, Optical, and IR Space Telescopes and Instruments, Munich, Germany, March 2000, 520 (2000).
- Jenniskens P., Betlem H. "Massive remnant of evolved cometary dust trail detected in the orbit of Halley-type comet 55P/Tempel-Tuttle," **Astrophysical Journal 531:**1161-1167 (2000).
- Jenniskens P., Butow S.J., Fonda, M. "The 1999 Leonid Multi-Instrument Campaign an early review," Earth, Moon and Planets 82-83:1-26 (2000).
- Jenniskens, P., Crawford C., Butow S.J., Nugent, D., Koop, M., Holman, D., Houston, J., Jobse, K., Kronk, G., Beatty, K. "Lorentz shaped comet dust trail cross section from new hybrid visual and video meteor counting technique implications for future Leonid storm encounters," **Earth, Moon and Planets 82-83:**191-208 (2000).
- Jenniskens P., Crawford C., Butow S. "Successful Hybrid Approach to Visual and Video Observations of the 1999 Leoind Storm," **WGN**, **the Journal of IMO 28:**58-63 (2000).
- Jenniskens P., Gustafson B.Å.S. "The rare 1932 dust trail encouner of 2000 November 17 as observed from aircraft," WGN, the Journal of IMO 28:209-211 (2000).
- Jenniskens P., Lacey M., Allan B.J., Self D.E., Plane J.M.C. "FeO "Orange Arc" emission detected in optical spectrum of Leonid persistent train," **Earth, Moon and Planets 82-83**:429-438 (2000).
- Jenniskens P., Laux C.O., Packan D.M., Wilson M., Fonda M. "Recent observations of Aerothermochemistry Effects in the Reentry Plasmas of Fast Leonid Meteors and Implications for the Origin of Life," **AIAA**, **2000-0582**:5 (2000).
- Jenniskens P., Lyytinen E. "Possible Ursid outburst on December 22, 2000," **WGN, the Journal of IMO 28**:221-226 (2000).
- Jenniskens P., Nugent D., Plane J.M.C. "The dynamical evolution of a tubular Leonid persistent train," **Earth, Moon and Planets 82-83:**471-488 (2000).
- Jenniskens P., Nugent D., Tedesco E., Murthy J. "1997 Leonid shower from space," **Earth, Moon and Planets 82-83**:305-312 (2000).

- Jenniskens P., Rairden R.L. "Buoyancy of the "Y2K" Persistent train and the trajectory of the 04:00:29 UT Leonid fireball," **Earth, Moon and Planets 82-83:**457-470 (2000).
- Jenniskens P., Rietmeijer F., Brosch N., Fonda M. (Editors) "Leonid Storm Research," **Earth, Moon and Planets 82-83** (2000).
- Jenniskens P., Wilson M.A., Packan d., Laux C.O., Krueger C.H., Boyd I.D., Popova O.P., Fonda M. "Meteors: a delivery mechanism of organic matter to the early Earth," **Earth, Moon and Planets 82-83**:57-70 (2000).
- Joblin, C., Abergel, A., Bregman, J., d'Hendecourt, L. "Spectroscopic diversity of the UIR bands as revealed by ISO. Towards a molecular carrier identification," **ISO beyond the peaks: The 2nd ISO workshop on analytical spectroscopy**, held 2-4 Feb. 2000, at VILSPA (2000).
- Johnson, J.R., S.W. Ruff, J. Moersch, T. Roush, K. Horton, J. Bishop, N.A. Cabrol, C. Cockell, P. Gazis, H.E. Newsom, and C. Stoker "Geological Characterization of Remote Field Sites Using Visible and Infrared Spectroscopy: Results from the 1999 Marsokhod Field Test," LPSC XXXI (2000).
- Jones, Harry and James Cavazzoni "Top-level Crop Models for Advanced Life Support Analysis," **30th** Intl. Conf. on Environ. Systems (ICES) (2000).
- Jones, Harry "Matching BIO-Plex Crop Food Production to Diet Requirements," **30th Intl. Conf. on Environ. Systems (ICES)** (2000).
- Joshi, M.M., Hollingsworth, J.L., Haberle, R.M. and Bridger, A.F.C. "An interpretation of Martian thermospheric waves based on analysis of a general circulation model," **Geophys. Letters 27:**613-616 (2000).
- Justtanont, K., Barlow, M.J., Tielens, A.G.G.M., Hollenbach, D., Latter, W. B., Liu, X.-W., Sylvester, R.J., Cox, P., Rieu, N.-Q. "ISO-LWS observations of rotational CO lines from C-rich objects: AFGL 2688, AFGL 618 and NGC 7027," **Astron. Astrophys. 360**:1117-1125 (2000).
- Kadel, S.D., F.C. Chuang, R. Greeley, J.M. Moore "Galileo SSI Team (2000) Geological history of the Tyre region of Europa: A regional perspective on Europan surface features and ice thickness," J. Geophys. Res. 105:22657-22669 (2000).
- Kim, S.J., M. Ruiz, G.H. Rieke, M.J. Rieke, and K. Zahnle "High temperatures in returning ejecta from the R impact of comet SL9," **Icarus 138:**164-172 (2000).
- Kliss, M., A.G. Heyenga, A. Hoehn, and L.S. Stodicek "Recent Advances in Technologies Required for a 'Salad Machine," **Advan. Space Res. 26 (2):**263-269 (2000).
- Kliss, M., A.G. Heyenga, A. Hoehn, and L.S. Stodieck "Toward the Development of a 'Salad Machine," **30th Intl. Conf. on Environ. Systems (ICES)** (2000).
- Koch, D.G., Dunham, E.W., Borucki, W.J., and Jenkins, J.M. "An Astronomical Test of CCD Photometric Precision," **NASA Conference Publications, CP-2000-209614:**95 (2000).

- Koch, D.G., W. Borucki, E. Dunham, J. Jenkins, L. Webster, and F. Witteborn "CCD photometry tests for a mission to detect Earth-size planets in the extended solar neighborhood," SPIE Conference Series, volume 4013, UV, Optical, and IR Space Telescopes and Instruments, Munich, Germany, March 2000, 508 (2000).
- Korycansky, D.G., K.J. Zahnle, and M.-M. Mac Low "High resolution calculations of asteroid impacts into the Venusian atmosphere," **Icarus 146:**387-403 (2000).
- Krot, A.N., A. Meibom, S.S. Russell, E. Young, C. Alexander, K., McKeegan, G. Lofgren, J. Cuzzi, J. Zipfel, and K. Keil "Chondrules of the very first generation in Bencubbin-like meteorites QUE94411 and Hammadah Al Hamra 237: origin by gas-liquid condensation," **LPSC XXXI** (2000).
- Ku, Y.E., L.D. Montgomery, H.C. Lee, B. Luna, and B.W. Webbon "Physiologic and functional responses of MS patients to body cooling," **Am. J. Phys. Med. Rehabil 79:**427-434 (2000).
- Laughlin, G. and F. Adams "The Frozen Earth: Binary Scattering Events and the Fate of the Solar System," Icarus 145:614-627 (2000).
- Laughlin, G. "Mining the Metal-Rich Stars for Planets," Astrophys. J. 545:1064-1073 (2000).
- Laval, B., S.L. Cady, J.C. Pollack, C.P. McKay, J.S. Bird, J.P. Grotzinger, D.C. Ford, and H.R. Bohm "Modern freshwater microbialite analogues for ancient dendritic reef structures," **Nature 407:**626-629 (2000).
- Le Blanc A.G., Murray I.S., Hawkes R.L., Worden, P., Campbell, M.D., Brown, P., Jenniskens, P., Correll, R.R., Montague, T., Babcock, D.D. "Evidence for transverse spread in Leonid meteors," **Mont. Not. R. Astron. Soc. 313**:L9-L13 (2000).
- Levison, H.F., M.J. Duncan, K. Zahnle, M. Holman, and L. Dones "Planetary Impact Rates from Ecliptic Comets," Icarus 143:415-420 (2000).
- Levri, J. and C. Finn "Energy Reuse by Matching Hot and Cold Streams in an Advanced Life Support System," **30th Intl. Conf. on Environ. Systems (ICES)** (2000).
- Lissauer, J.J. and D.N.C. Lin "Diversity of Planetary Systems: Formation Scenarios and Unsolved Problems," Extrasolar Planets to Cosmology: The VLT Opening Symposium:377-390. (2000).
- Lissauer, J.J., and R.G. French "HST High-Resolution Backscatter Image of Saturn's G Ring," **Icarus 146**:12-18 + cover. (2000).
- Lissauer, J.J., G.W. Marcy and S. Ida "Extrasolar Planets," **Proc. Nat. Acad. Sci. USA 97:**12,405-12,406. (2000).
- Lissauer, J.J., L. Dones, and K. Ohtsuki "Origin and Evolution of Terrestrial Planet Rotation" IN **Origin of the Earth and Moon**, Edited by: R.M. Canup and K. Right, Tucson: University of Arizona Press, pp 101-112 (2000).

- Lissauer, J.J. "Planetary Formation and the Abundance of Habitable Planets" IN Bioastronomy '99 A New Era in Bioastronomy, ASP Conference Series 213, Edited by: G.A. Lemarchand and K. Meech, Sheridan: Chelsea, MI, pp 57-64 (2000).
- Macintyre, I.G., Prufert-Bebout, L. & Reid, P.R. "The role of endolithic cyanobacteria in the formation of lithified laminae in Bahamian stromatolites," Sedimentology 47:915-921 (2000).
- Malhotra, S., Hollenbach, D., Helou, G., Silbermann, N., Valjavec, E., Rubin, R.H., Dale, D., Hunter, D., Lu, N., Lord, S., Dinerstein, H., and Thronson, H. "Probing the Interstellar Medium in Early-Type Galaxies with Infrared Space Observatory Observations," Astrophys. J. 543(2):634-643 (2000).
- Marinova, M.M., C.P. McKay and H. Hashimoto "Warming Mars using artificial super-greenhouse gases," J. Brit. Interplanet. Soc. 53:235-240 (2000).
- Markwick, A.J., Millar, T.J. and Charnley, S.B. "On the Abundance Gradients of Organic Molecules Along the TMC-1 Ridge," Astrophys. J. 535:256 (2000).
- Martin, T.Z., Murphy, J. and Hollingsworth, J.L. "Mars Global Atmospheric Thermal Behavior from the MGS Horizon Science Experiment," Geophys. Res. Abs. 2:96 (2000).
- McCreight, Craig R., Fowler, Albert M., Greene, Thomas P., Greenhouse, Matthew A., Hall, Donald N., Long, Knox S.; MacKenty, John W., Martineau, Robert J.; Pipher, Judith L., Ressler, Michael E., and Young, Erick T. "Detector requirements for NGST," SPIE Conference volume 4013, UV, Optical, and IR Space Telescopes and Instruments, Munich, Germany, March 2000, 800-809 (2000).
- McEwen, A.S., M.J.S. Belton, H.H. Breneman, S.A. Fagents, P.Geissler, R.Greeley, J.W. Head, G.Hoppa, W.L. Jaeger, T.V. Johnson, L. Keszthelyi, K.P. Klaasen, R. Lopes-Gautier, K.P. Magee, M.P. Milazzo, J.M. Moore, R.T. Pappalardo, C.B. Phillips, J. Radebaugh, G. Schubert, P. Schuster, D.P. Simonelli, R. Sullivan, P.C. Thomas, E.P. Turtle, D.A. Williams "Galileo at Io: Results from High-Resolution Imaging," Science 288:1192-1198 (2000).
- McKay, C.P. "Astrobiology: The search for life beyond the Earth, in Many Worlds" IN The New Universe, Extraterrestrial Life and the Theological Impliciations, Edited by: S. Dick, Templeton Press, Philidelphia, pp 45-58 (2000).
- McKay, C.P. (book review) "Rare Earth: Why Complex Life is Uncommon in the Universe by Peter Ward and Donald Brownlee," Science 288:625 (2000).
- Mckay, C.P. (book review) "Stepping Stones: Evolving the Earth and its Life by Stephen Drury," EOS (2000).
- McKay, C.P. "Climate and life on Mars" IN From Weather Forecasting to Exploring the Solar System, Edited by: C. Boutron, EDP Sciences, Les Ulis, France, ERCA Vol 4., pp 313-324 (2000).
- Mckay, C.P. "Flowers for Mars," **The Planetary Report 20** (2000).

- McKay, C.P. "Thickness of tropical ice and photosynthesis on a snowball Earth," **Geophys. Res. Lett. 27**:2153-2156 (2000).
- Meibom, A., S. J. Desch, A. N. Krot, J. N. Cuzzi, M. I. Petaev, L., Wilson, and K. Keil "Large scale thermal events in the solar nebula recorded in Fe, Ni metal condensates in primitive meteorites," **Science 288**:839-841 (2000).
- Melnick, G.J., M.L.N. Ashby, R. Plume, E.A. Bergin, D.A. Neufeld, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, J.E. Howe, S.C. Kleiner, D.G. Koch, B.M. Patten, R. Schieder, R.L. Snell, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, and Y.F. Zhang "Observations of Water Vapor toward Orion BN/KL," Astrophys. J. Letters 539:L87 (2000).
- Melnick, Gary J., John R. Stauffer, Matthew L.N. Ashby, Edwin A. Bergin, Gordon Chin, Neal R. Erickson, Paul F. Goldsmith, Martin Harwit, John E. Howe, Steven C. Kleiner, David G. Koch, David A. Neufeld, Brian M. Patten, René Plume, Rudolf Schieder, Ronald L. Snell, Volker Tolls, Zhong Wang, Gisbert Winnewisser, and Yun Fei Zhang "The Submillimeter Wave Astronomy Satellite: Science Objectives and Instrument Description," **Astrophys. J. Letters 539:**L77 (2000).
- Meyer, A.W., S.M. Smith, and C.T. Koerber "Far-infrared BRDFs and reflectance spectra of candidate SOFIA telescope, cavity and focal-plane instrument surfaces," **Airborne Telescope Systems 4014**:263-274 (2000).
- Mihalov, J. D., Fischer, H. M., Pehlke, E., Lanzerotti, L. J. "Energetic trapped electron measurements from the Galileo Jupiter probe," **Geophysical Research Letters 27:**2445-2448 (2000).
- Mischna, Michael A., Kasting, James F., Pavlov, Alex, Freedman, Richard "Influence of carbon dioxide clouds on early martian climate," **Icarus 145:**546-554 (2000).
- Morbidelli, A., J.Chambers, J.I.Lunine, J.M.Petit, F.Robert, G.B.Valsecchi and K.E.Cyr "Source Regions and Timescales for the Delivery of Water on Earth," **Meteoritics 35:**1309-1320 (2000).
- Morris, R.V., Golden, D.C., Bell, J.F. III, Shelfer, T.D., Scheinost, A.C., Hinman, N.W., Furniss, G., Mertzman, S.A., Bishop, J.L., Ming, D.W., Allen, C.C., and Britt, D.T. "Mineralogy, composition, and alteration of Mars Pathfinder rocks and soils: Evidence from multispectral, elemental, and magnetic data on terrestrial analogue, SNC meteorite, and Pathfinder samples," **J. Geophys. Res. 105**:1757-1817 (2000).
- Mulloth, L.M. and J.E. Finn "A Solid-state Compressor for Integration of CO2 Removal and Reduction Assemblies," **30th Intl. Conf. on Environ. Systems (ICES)** (2000).
- Murad E. and Bishop J.L. "The infrared spectrum of synthetic akaganéite, β-FeOOH," **American Mineralogist 85**:716-721 (2000).
- Murray I.S., Beech, M., Taylor, M.J., Jenniskens, P., Hawkes R.L. "Comparison of 1998 and 1999 Leonid light curve morphology and meteoroids structure," **Earth, Moon and Planets 82-83:**351-367 (2000).

- Nakamura, R., Fujii Y., Ishiguro M., Morishige K., Yokogawa S., Jenniskens P., Mukai T. "The discovery of a faint glow of scattered sunlight from the dust trail of the Leonid parent comet 55P/Tempel-Tuttle.," **Astrophys. J. 540**:1172-1176 (2000).
- Neufeld, D.A., J.R. Stauffer, E.A. Bergin, S.C. Kleiner, B.M. Patten, Z. Wang, M.L.N. Ashby, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, J.E. Howe, D.G. Koch, R. Plume, R. Schieder, R.L. Snell, V. Tolls, G. Winnewisser, Y.F. Zhang, and G.J. Melnick "Submillimeter Wave Astronomy Satellite Observations of Water Vapor toward Comet C/1999 H1 (Lee)," Astrophys. J. Letters 539:L1 (2000).
- Neufeld, D.A., M.L.N. Ashby, E.A. Bergin, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, J.E. Howe, S.C. Kleiner, D.G. Koch, B.M. Patten, R. Plume, R. Schieder, R.L. Snell, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, Y.F. Zhang, and G.J. Melnick "Observations of Absorption by Water Vapor toward Sagittarius B2," **Astrophys. J. Letters 539:**L111 (2000).
- Neufeld, D.A., R.L. Snell, M.L.N. Ashby, E.A. Bergin, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, J.E. Howe, S.C. Kleiner, D.G. Koch, B.M. Patten, R. Plume, R. Schieder, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, Y.F. Zhang, and G.J. Melnick "Observations of Interstellar Water Vapor in Outflow Regions," Astrophys. J. Letters 539:L107 (2000).
- New, M.H. and Pohorille, A. "An Inherited Efficiencies Model of non-genomic evolution," **Simulation Practice and Theory 8:99-108** (2000).
- Newsom, H.E., Bishop, J.L., Cockell, C., Roush, T. and Johnson J.R. "The search for life on Mars in surface samples: lessons from the 1999 Marsokhod field test," **LPSC XXXI**, abs. #1931 (2000).
- Nicholson, P. D., R. C. French, E. Tollestrup, J. N. Cuzzi, J. Harrington, K., Matthews, O. Perkovic, and R. J. Stover "Saturn's rings I: Optical depth profiles from the 28 Sgr occultation," **Icarus 145:**474-501 (2000).
- Noll, K.S., Geballe, T.R., Leggett, S.K., and Marley, M.S. "The Onset of Methane in L Dwarfs," **Astrophys. J. Letters 541:**L75-L78 (2000).
- Norris, J.P., Bonnell, J.T., Marani G.F., and Scargle, J.D. "GLAST, GRBs, and Quantum Gravity," **Proc. 5th Huntsfille Gamma-Ray Burst Symposium** (2000).
- Novak, G., Dotson, J.L., Dowell, C.D., Hildebrand, R.H., Renbarger, T., and Schleuning, D.A. "Submillimeter Polarimetric Observations of the Galactic Center," **Astrophys. J. 529(1):**241-250 (2000).
- Onaka, T., Chan, K-W., Mizutani, M., Roellig, T.L., Okumura, K., Shibai, H., and Nakagawa, T. "The UIR Emission Bands and the FIR Emission Observed by IRTS and ISO," **ASP Conference Series 231**:183-184 (2000).
- Ootsubo, T., Onaka, T., Yamamura, I., Tanabe, T., Roellig, T. L., Chan, K.-W., and Matsumoto, T. "IRTS Observations of the Mid-Infrared Spectrum of the Zodiacal Emission," **Advan. Space Res. 25(11):**2163-2166 (2000).

- Ortiz, W., K. Wignarajah, and J.D. Smith "Inhibitory Effect of Hypergravity on Photosynthetic Carbon Dioxide Fixation in Euglena gracilis," **Journal of Plant Physiology 157(2):**231-234 (2000).
- Palumbo, M. E., Pendleton, Y. J., and Strazzulla, G. "Hydrogen Isotopic Substitution Studies of the 2165 cm-1 (4.62 μm) "XCN," **Astrophys. J. Letters 542:890** (2000).
- Palumbo, M.E., Strazzulla, G., Pendleton, Y. J., and Tielens, A. G. G. M. "ROCN species produced by ion irradiation of ice mixtures: Comparison with astronomical observations," **Astrophys. J. 534:**801 (2000).
- Paque, J.M., Lofgren, G.E. and Le, L. "Crystallization of calcium-aluminum-rich inclusions: Experimental studies on the effects of repeated heating events," **Meteoritics and Planetary Science 35**:363-371 (2000).
- Pavlov, Alexander A., Kasting, James F., Brown, Lisa L., Rages, Kathy A., Freedman, Richard "Greenhouse warming by CH4 in the atmosphere of early Earth," **Journal of Geophysical Research 105(E5)**:11981-11990 (2000).
- Perez-Chavez, I., R. Navarro-Gonzalez, C.P. McKay, and L. Cruz-Kuri "Tropical alpine environments: A plausible analog for ancience and future Mars" IN **Astrobiology**, Edited by: J. Chela-Flores, G.A. Lemarchand, and J. Oro, Kluwer Scientific, Dordrecht, The Netherlands (2000).
- Pisharody, S., M. Moran, J.W. Fisher, M. Tleimat "Incineration of Inedible Biomass in a Regenerative Life Support System Developmental Efforts at NASA Ames Research Center," **30th Intl. Conf. on Environ. Systems (ICES)** (2000).
- Plume, R., F. Bensch, J.E. Howe, M.L.N. Ashby, E.A. Bergin, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, S. Kleiner, D.G. Koch, D.A. Neufeld, B.M. Patten, R. Schieder, R.L. Snell, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, Y.F. Zhang, K. Reynolds, R. Joyce, C. Tavoletti, G. Jack, C.J. Rodkey, and G.J. Melnick "Large-scale 13CO J = 54 and [C I] Mapping of Orion A," **Astrophys. J. Letters** 539:L133 (2000).
- Podolak, M., Podolak, J.I., and Marley, M.S. "Further investigations of random models of Uranus and Neptune," **Planetary Space Science 48:**143-151 (2000).
- Poulet, F. "A scenario of Saturn's ring formation," **DDA Meeting**, 08.08 (2000).
- Poulet, F. and S. Jancart "On the dynamical stability of Saturn's F ring," DDA Meeting, 07.02 (2000).
- Poulet, F., B. Sicardy, C. Dumas, L. Jorda, and D. Tiphene "The crossings of Saturn ring plane by the Earth in 1995: Ring thickness," **Icarus 145:**147-165 (2000).
- Poulet, F., B. Sicardy, P.D. Nicholson, E. Karkoschka, and J. Caldwell "Saturn's ring-plane crossings of August and November 1995: A model for the new F-ring objects," **Icarus 144:**135-148 (2000).
- Poulet, F., J. Cuzzi, L.Dones, P. Drossart, and R.G. French "Saturn's rings phase curves: Implications for surface of particles," **Bulletin of the American Astronomical Society 32:**1088 (2000).

- Quinn, R.C., A.P. Zent, C.P. McKay, and R.M. Haberle "The Stability of Liquid-Water Films on the Surface of Mars," Bulletin of the American Astronomical Society 32(2):1119 (2000).
- Rages, K.A., H.B. Hammel, G.W. Lockwood, and M. Marley "How I spent my summer vacation on Uranus - HST images," Bulletin of the American Astronomical Society 32:1005 (2000).
- Rairden R.L., Jenniskens P., Laux C.O. "Search for organic matter in Leonid meteoroids," Earth, Moon and Planets 82-83:71-80 (2000).
- Rannou, P, C. Ferrari, K. Rages, M. Roos-Serote, and M. Cabane "Characterization of aerosols in the detached haze layer of Titan," Icarus 147:267-281 (2000).
- Ratkiewicz, R., A. Barnes, and J.R. Spreiter "Local interstellar medium and modeling the heliosphere," J. Geophys. Res. 105:25,021-25,031 (2000).
- Reid, R.P., Visscher, P.T., Decho, A.W., Stolz, J., Bebout, B.M., MacIntyre, I.G., Paerl, H.W., Pinckney, J.L., Prufert-Bebout, L., Steppe, T.F. and Des Marais, D.J. "The Role of Microbes in Accretion, Lamination and Early Lithification of Modern Marine Stromatolites," Nature 406:989-992 (2000).
- Reynolds, J.K., D. Catling, R.C. Blue, N.I. Maluf, and T. Kenny "Packaging a piezoresistive pressure sensor to measure low absolute pressures over a wide sub-zero temperature range," Sensors and Actuators A83:142-149 (2000).
- Rietmeijer F.J.M., Jenniskens, P. "Recognizing Leonid meteoroids among the collected stratospheric dust," Earth, Moon and Planets 82-83:505-524 (2000).
- Rivera, E.J., and J.J. Lissauer "Stability Analysis of the Planetary System Orbiting u Andromedae," Astrophys. J. 530:454-463 (2000).
- Rivkina, E.M., E.I. Friedmann, C.P. McKay, and D.A. Gilichinsky "Metabolic activity of permafrost bacteria below the freezing point," Appl. Environ. Microbio. 66:3230-3233 (2000).
- Rossano G.S., Russell R.W., Lynch D.K., Tessensohn T.K., Warren, D., Jenniskens P. "Observations of Leonid meteors using a mid-wave infrared imaging spectrograph," Earth, Moon and Planets 82-83:81-92 (2000).
- Roush, T.L. and R.C. Hogan "Mars Global Surveyor Thermal Emission Spectrometer Observations of Phobos," LPSC XXXI, abstract #1598 (2000).
- Roush, T.L. "Physical State of Ices in the Outer Solar System," Workshop on Photolysis and Radiolysis of Outer Solar System Ices, 27-29 March 2000, Johns Hopkins University Applied Physics Laboratory, Baltimore MD (2000).
- Sandford, S.A., Bernstein, M.P., Allamandola, L.J., Gillette, J.S., and Zare, R.N. "Deuterium Enrichment of PAHs by Photochemically Induced Exchange with Deuterium-rich Cosmic Ices," Astrophys. J. **538**:691-697 (2000).

- Sandford, S., Greene, T.P., Allamandola, L., Arno, R., Bregman, J., Cox, S., Davis, P.K., Gonzales, A., Haas, M., Hanel, R., Hines, M., Hudgins, D., Jackson, R., Kittel, P., Lozier, D., Maa, S., and McCreight, C. "An Explorer-class Astrobiology Mission," SPIE Conference Series, volume 4013, **UV**, **Optical**, **and IR Space Telescopes and Instruments**, Munich, Germany, March 2000, 604-615 (2000).
- Sarrazin, P., D. Blake, D. Bish, D. Vaniman, S. Chipera, S.A. Collins, and S.T. Elliott "In situ investigation of ices and hydrous minerals at the lunar poles using a combined X-ray fluorescence and diffraction instrument," J. Phys. IV France 10:Pr10-343-Pr10-352 (2000).
- Saumon, D., Geballe, T.R., Leggett, S.K., Marley, M.S., Freedman, R.S., Lodders, K., Fegley, B., Jr., Sengupta, S.K. "Molecular Abundances in the Atmosphere of the T Dwarf GL 229B," **Astrophys. J. 541(1):**374-389 (2000).
- Scargle, J., Norris, J., Marani, G., and Bonnell, J. "Attributes of GRB Pulses: An Improved Bayesian Blocks Algorithm for Binned Data," **Proc. 5th Huntsfille Gamma-Ray Burst Symposium** (2000).
- Schenk, P.M. and J.M. Moore "Stereo topography of the south polar region of Mars: Volatile inventory and Mars Polar Lander landing site," **J. Geophys. Res. 105**:24529-24546 (2000).
- Schleuning, D.A., Vaillancourt, J.E., Hildebrand, R.H., Dowell, C.D., Novak, G., Dotson, J.L., and Davidson, J.A. "Probing the Magnetic Field Structure in the W3 Molecular Cloud," **Astrophys. J.** 535(2):913-927 (2000).
- Schweighofer, K. and Pohorille, A. "Computer simulations of ion channel gating: the M2 channel of Influenza A virus," **Biophysics Journal 78:**150-163 (2000).
- Showman, A.P. and T.E. Dowling "Nonlinear simulations of Jupiter's 5-micron hot spots," **Science 289:**1737-1740 (2000).
- Shu, F., Laughlin, G., Lizano, S., Galli, D. "Singular Isothermal Disks: I. Linear Stability Analysis," Astrophys. J. 535:190-210 (2000).
- Shuping, R.Y., Snow, T.P., Chiar, J.E., and Kerr, T. "Solid-State CO toward Rho Ophiuchi Elias 25: Ice Thresholds Revisited," **Astrophys. J. 529:**932-935 (2000).
- Slavin, Jonathan D., McKee, Christopher F., and Hollenbach, David J. "Photoionization of Galactic Halo Gas by Old Supernova Remnants," **Astrophys. J. 541(1):**218-233 (2000).
- Snell, R.L., J.E. Howe, M.L.N. Ashby, E.A. Bergin, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, S.C. Kleiner, D.G. Koch, D.A. Neufeld, B.M. Patten, R. Plume, R. Schieder, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, Y.F. Zhang, and G.J. Melnick "Submillimeter Wave Astronomy Satellite Observations of Extended Water Emission in Orion," Astrophys. J. Letters 539:L93 (2000).

- Snell, R.L., J.E. Howe, M.L.N. Ashby, E.A. Bergin, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, S.C. Kleiner, D.G. Koch, D.A. Neufeld, B.M. Patten, R. Plume, R. Schieder, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, Y.F. Zhang, and G.J. Melnick "The Distribution of Water Emission in M17SW," Astrophys. J. Letters 539:L97 (2000).
- Snell, R.L., J.E. Howe, M.L.N. Ashby, E.A. Bergin, G. Chin, N.R. Erickson, P.F. Goldsmith, M. Harwit, S.C. Kleiner, D.G. Koch, D.A. Neufeld, B.M. Patten, R. Plume, R. Schieder, J.R. Stauffer, V. Tolls, Z. Wang, G. Winnewisser, Y.F. Zhang, and G.J. Melnick "Water Abundance in Molecular Cloud Cores," Astrophys. J. Letters 539:L101 (2000).
- Sprague, A.L., T.L. Roush, R.A. Downs, and K. Righter "Response to comment on Comparison of laboratory emission spectra with Mercury telescopic data," *Icarus* 143:409-411 (2000).
- Spurny P., Betlem, H., van 't Leven J., Jenniskens P. "Atmospheric behavior and extreme beginning heights of the thirteen brightest photographic Leonid meteors from the ground-based expedition to China," **Meteoritics & Plan. Science 35:**243-249 (2000).
- Steiman-Cameron, T.Y., Wolfire, M.G., and Hollenbach, D.J. "Morphology of the Milky Way's Spiral Arms," **Bulletin of the American Astronomical Society Meeting 197**, #04.14 (2000).
- Stoker, C. and B. Kanefsky "The Superresolved Super Pan: Improved Resolution Of The Mars Pathfinder Landing Site Using Superresolution On The IMP Super Pan Data Set," **LPSC XXXI**, abstract #1753 (2000).
- Stoker, C.R. and E. Zbinden "Virtual Reality on Mars Pathfinder and Mars Polar Lander," **RTO SCI** symposium on Advanced Mission Management and System Integration Technologies for Improved Tactical Operations: at Scuola di Guerra Aerea, Florence Italy, 27-29 Sept. 1999 (2000).
- Störzer, H. and D. Hollenbach "Optical Line Emission from Photodissociation Regions," **Astrophys. J. 539(2):**751-759 (2000).
- Taylor M.J., Gardner L.C., Murray I.S., Jenniskens P. "Jet-like structures and wake in MgI (518 nm) images of 1999 Leonid storm meteors," **Earth, Moon and Planets 82-83:**379-389 (2000).
- Traub, W.A., Carleton, N.P., Bregman, J.D. "Third Telescope Project at the IOTA Interferometer," **Proceedings of SPIE: Interferometry in Optical Astronomy 4006:**715 (2000).
- Van Kerckhoven, C., Hony, S., Peeters, E., Tielens, A.G.G.M., Allamandola, L.J., Hudgins, D.M., Cox, P., Roelfsema, P.R., Voors, R., Waelkens, C., Waters, R., and Wesselius, P.R. "The CCC Bending Modes of PAHs: A New Emission Plateau from 15 to 20 µm," **Astron. Astrophys. 357:**1013-1019 (2000).
- Visscher, P.T., R.P. Reid and B.M. Bebout "Microscale observations of sulfate reduction: Correlation of microbial activity with lithified micritic laminae in modern marine stromatolites," **Geology 28(10)**:912-922 (2000).

- Weber, A.L. "Sugars as the optimal biosynthetic carbon substrate of aqueous life throughout the Universe," **Origins Life Evol. Bios. 30:**33-43 (2000).
- Whittet, D.C.B., Pendleton, Y.J., Gibb, E.L., Boogert, A.C.A. Boogert, Chiar, J.E., and Nummelin, A. "Observational Constraints on the Abundance of "XCN" in Interstellar Grain Mantles," **Astrophys. J. 550**:793 (2000).
- Wignarajah, K., S. Pisharody, and J.W. Fisher "Can Incineration Technology Convert CELSS Wastes to Resources for Crop Production? A Working Hypothesis and Some Preliminary Findings," **Advan. Space Res. 26**:327-333 (2000).
- Wignarajah, K., S. Pisharody, J.W. Fisher "Optimization of Waste Derived Elemental Use to Meet Demands of Crop Production of Selected BIO-Plex Crops," **30th Intl. Conf. on Environ. Systems** (ICES) (2000).
- Witteborn, F.C., T.L. Roush, M. Cohen "Thermal Emission Spectroscopy of 1 Ceres: Evidence for Olivine" IN **Thermal Emission Spectroscopy and Analysis of Dusts, Disks, and Regoliths**, Edited by: M.L. Sitko, A.L. Sprague, and D.K. Lynch, Astron. Soc. Pacific Conf. Series, San Francisco, 196, pp 197-203 (2000).
- Wood, K.S., P.S. Ray, R.M. Bandyopadhyay, M.T. Wolff, G. Fritz, P. Hertz, M.P. Kowalski, M.N. Lovellette, D. Yentis, E. Bloom, B. Giebels, G. Godfrey, K. Reilly, P. Saz Parkinson, G. Shabad, and J. Scargle "USA and RXTE Observations of a Variable Low-Frequency QPO in XTE J1118+480," Astrophys. J. Letters 544:L45-L48 (2000).
- Wooden, D., Butner, H., Harker, D., and Woodward, C. "Mg-Rich Silicate Crystals in Comet Hale-Bopp: ISM Relics or Solar Nebula Condensates?," Icarus 143:126-137 (2000).
- Wooden, D., Harker, D., and Woodward, C. "Crystalline Silicates, Comets, and Protoplanetary Disk Evolution," **Thermal Emission Spectroscopy and Analysis of Dust, Disks, and Regoliths 196**:99-108 (2000).
- Wuchterl, G., T. Guillot, and J.J. Lissauer "Giant Planet Formation" IN **Protostars and Planets IV**, Edited by: V. Mannings, A.P. Boss and S.S. Russell, Tucson: University of Arizona Press, pp 1081-1109. (2000).
- Yaoi, T., P. Laksanalamai, A. Jiemjit, H. Kagawa, T. Alton, and J. Trent "Cloning and Characterization of ftsZ and pyrF from the Archaeon Thermoplasma acidophilum," **Biochemical and Biophysical Research Communications 275:**936-945 (2000).

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